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Mathematical Model and Analysis of the Tactical Unmanned Ground Vehicle (TUGV) using Computer Simulation

by

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The purpose of this thesis is to mathematically model the Tactical Unmanned Ground Vehicle (TUGV) in the Janus(A) Combat Model. The TUGV has three sensors, an optical, thermal, and acoustic sensor. Algorithms currently exist in Janus(A) for both optical and thermal sensors. An acoustic detection algorithm exists although not available to all Janus(A) system users. This thesis examines the TUGV prototype, explains the Janus(A) TUGV model, discusses existing acoustic detection algorithms, and tests the TUGV model in a scenario driven experiment.

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ACRONYM LIST

ANOVA....................................Analysis of Variance

BFV....................................Bradley Fighting Vehicle

BNOISE....................................Blast Noise Prediction

CEP....................................Circular Error Probability

CDNL.................C-Weighted Day/Night Average Sound Level

CFV....................................Cavalry Fighting Vehicle

COEA....................................Cost and Effectiveness Analysis

COEE....................................Concept of Employment Evaluation

COIC.................Critical Operational Issues and Criteria

DEA....................................Drug Enforcement Agency

DEC....................................Digital Equipment Corporation

DOD....................................Department of Defense

EUTE....................................Early User Test and Evaluation

FDTE....................................Force Development Test and Evaluation

FLOT....................................Friendly Line of Troops

FLIR....................................Forward Looking Infrared Radar

FM....................................Frequency Modulation

FOT....................................Follow-on Operational Test

FOV....................................Field of View

GPS....................................Global Positioning System

HMMWV...............High Mobility Multipurpose Wheeled Vehicle

IOT....................................Initial Operational Test

KPH....................................Kilometers per Hour

LABCOM....................................US Army Laboratory Command

LLL....................................Lawrence Livermore Laboratory

LOS..Line of Sight

LTC..Lieutenant Colonel

LUT..Limited User Test

MBU..Mobile Base Unit

MOA..................................Memorandum of Agreement

MOE................................Measure of Effectiveness

M-T-M..Model Test Model

NBC.......................Nuclear, Biological, and Chemical

NL...Noise Level

OCU....................................Operator Control Unit

OT & E....................Operational Testing and Evaluation

PH/PK................Probability of Hit/Probability of Kill

PM..Project Manager

REMBASS..........Remotely Monitored Battlefield Sensor System

RSTA.....Reconnaissance, Surveillance, and Target Acquisition

S3TO...Signature, Sensors, and Signal Processing Tech. Office

SOTAS.....................Standoff Target Acquisition System

SPL....................................Sound Pressure Level

STV...........................Surrogate Teleoperated Vehicle

TEC.......Test and Evaluation Command Experimentation Center

TEMP.........................Test and Evaluation Master Plan

TRAC.................................TRADOC Analysis Command

TRADOC.........................Training and Doctrine Command

TUGV.........................Tactical Unmanned Ground Vehicle

UCCATS.........Urban Combat Computer Assisted Training System

USA-CERL..US Army Construction Engineering Research Laboratory

USAIS....................................US Army Infantry School

USAREUR..US Army Europe

USMA...........................United States Military Academy

WSMR..............................White Sands Missile Range

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I. INTRODUCTION

A. GENERAL

The overall acquisition process for a material system within the Department of Defense (DoD) is an intensive and often lengthy process. The process is multi-faceted, yet consists of four distinct phases which occur after the need for such a new system surfaces. The first phase is the Concept Exploration and Definition phase. This phase investigates the role, mission, and functions of the new system. The next phase, the Demonstration and Validation phase, examines the suitability of the system in question to perform the required mission. Next, the Engineering and Manufacturing Development phase explores technical issues. The final two phases deal with the production, deployment and support required to field the new system. Prior to a phase beginning, developers conduct a milestone review, referred to as Milestone 0, I, II, III, and IV, respectively. Prior to Milestone III, various agencies perform Operational Testing and Experimentation (OT & E). The OT & E is a general term used to describe the examination of a new material system under a realistic operational condition and environment by a group selected to represent the actual user. [Ref. 1]

While all phases of the acquisition process are important, the Operational Testing and Experimentation phase which takes place during the Concept Exploration and Definition, Demonstration and Validation, and Engineering and Manufacturing Development phases is critical. The OT & E, through an intense process, shows if or how well a new material system will perform its assigned mission. Thus, OT & E directly impacts on the success or failure of a new material system. The intense process of operational testing consists of Early User Test and Evaluation (EUTE), Limited User Test (LUT), the Initial Operational Test (IOT), and Follow-on Operational Test (FOT). While this process may seem complicated, it is based on a logical sequence of events. The EUTE is designed to test the basic concept of the material system, to examine training and logistical requirements, to determine interoperability requirements, and to identify future testing requirements. The LUT provides a data source for operational assessments in support of reviews prior to the IOT. The Initial Operational Test determines the effectiveness and suitability for the user of the system under examination. The FOT actually occurs during or in conjunction with the production phases. The goal of FOT is to ensure that deficiencies identified by previous operational tests were corrected. [Ref. 1]

Presently, the United States Army and Marine Corps have a new enemy detection and target acquisition system in the

operational testing and experimentation portion of the acquisition process. This new system is the Tactical Unmanned Ground Vehicle (TUGV). The TUGV is an unmanned, robotically-controlled system designed primarily to detect enemy targets and concentrations. The TUGV consists of two major components, a remotely operated unmanned Mobile Base Unit (MBU) and a manned Operator Control Unit (OCU) together constitute the TUGV system. The High Mobility Multipurpose Wheeled Vehicle (HMMWV) serves as the platform for both the MBU and OCU.

The primary mission for the TUGV is to operate continuously over extended periods of time while conducting reconnaissance, surveillance, and target acquisition (RSTA). In order for the MBU to manage this RSTA, it will be equipped with several sensors. These sensors include optical, thermal, acoustic, and Nuclear, Biological, and Chemical (NBC) detection devices. [Ref. 2] In terms of RSTA, this thesis will deal primarily with the optical, thermal, and acoustic sensors.

B. THESIS OBJECTIVE

The objective of this thesis is to model the TUGV in Janus(A) Combat Simulation Model by using the Model-Test-Model (M-T-M) concept. The M-T-M concept is a tool designed to exploit both combat simulation modeling and field testing capabilities within the U.S. Army analysis and operational

planning agencies. Model-Test-Model consists of five phases: long-term planning phase, pretest modeling phase, field test phase, post-test modeling phase, and the accreditation phase. This thesis deals primarily with combat simulation modeling of the pretest modeling phase. By conducting the pretest combat simulation modeling prior to a field test, the analyst can gain useful information in planning and designing the field test. For example, while conducting modeling experiments in the Janus(A) combat simulation, the analyst may determine an optimal distance to place the TUGV in front of his forces or where best to halt movement of the TUGV and his forces to prevent the TUGV and his forces from getting killed. [Ref. 3] Also, the analyst can help set objectives like how many detections the TUGV should get for the field tests by conducting combat simulation modeling prior to the field tests.

This thesis will first describe the TUGV and its design on the Janus(A) combat model. Then a theoretical discussion of acoustics and how sound propagates in reference to varying weather conditions. Following the theoretical analysis of sound the current sound algorithm used in the model described in this thesis will be analyzed by first considering the theory behind its development then the actual code. The discussion concerning sound will conclude with a theoretical discussion of modifying the current sound algorithm by considering elements from the Urban Combat Computer Assisted

Training System (UCCATS) and Blast Noise Prediction (BNOISE) sound algorithms; which are two other models which currently use sound. Particularly, this thesis will consider the temperature inversion which BNOISE takes into account. Finally, an analysis of the number of detections and survivability is done by comparing scenarios with and without the TUGV and how varying the weather conditions effect the number of detections. [Ref.4,Ref.5]

C. ISSUES

This thesis directly supports the United States Army Test and Evaluation Command Experimentation Center (TEC) by giving TEC critical modeling information prior to the actual field tests during what is referred to as the Early User Test and Experimentation (EUTE). The EUTE of the TUGV includes both Army and Marine units. The Army has one mechanized infantry platoon, and the Marines have one dismounted platoon. The Army and Marine platoons, known as the 'blue' forces, oppose the enemy, known as the 'red' force. In all scenarios of the EUTE, the red force has four Cavalry Fighting Vehicles (CFVs). The EUTE is now scheduled to occur in February 1996. [Ref. 6]

A specific issue addressed in this research is whether or not a realistic portrayal of the actual TUGV can be represented in the Janus(A) model. This issue will be answered through applicable discussion and the corresponding Janus(A) model representation. In regards to the efficiency

and effectiveness of the TUGV design, specific issues to be addressed include the following:

(1) determine whether or not the proposed scenarios are feasible and assist in examining the difference between a unit with or without a TUGV,

(2) determine whether a unit having a TUGV significantly increases its detection capabilities,

(3) determine how much varying the weather conditions effect the acoustic detection capabilities of the TUGV, and

(4) identify whether or not it is cost effective to add sound algorithms to the existing Janus(A) model [Ref. 7:p. 6].

D. BACKGROUND OF SENSORY PLATFORMS

Prior to examining a new sensory system, one should examine past sensory systems such as the Remotely Monitored Battlefield Sensory System (REMBASS) and the Standoff Target Acquisition System (SOTAS) in order to take advantage of any of these systems strengths and avoid any of their weaknesses. REMBASS supported battalion level and above operations and consisted of three basic sensors: acoustic/seismic, magnetic, and infrared. A team emplaced the sensors where they could best cover the area of operations. The range of the magnetic and infrared sensors was limited by line-of-sight (LOS). The capabilities of REMBASS sensors are listed in Table 1. An example of a limitation to REMBASS is that an animal may activate the seismic and infrared sensors. Probably, the greatest limitation of REMBASS is that it is a stationary

device which can not be moved rapidly from one location to another. The TUGV in this model is remote and can be moved from point A to point B in relatively short period of time.

TABLE 1 REMBASS SENSORS

CAPABILITIES OF REMBASS SENSORS		
SENSOR	**TARGET**	**DISTANCE**
ACOUSTIC/SEISMIC	VEHICLES/PERSONNEL	500/50 m
MAGNETIC	VEHICLES/PERSONNEL	500/50 m
INFRARED	ANY	45-50 m

In addition to the REMBASS, a separate airborne system, the Standoff Target Acquisition System (SOTAS) once existed. The SOTAS was a helicopter mounted side looking airborne radar that flew 25 kilometers behind the Friendly Line Of Troops (FLOT), detecting out to 75 kilometers. However, SOTAS never had any type of acoustic or thermal device on it; therefore, it was limited to optical and its radar capabilities. This system was at a disadvantage since it had no acoustic or thermal detection device. [Ref. 8]

E. WHY INCORPORATING SOUND IS NECESSARY

The study of military target acquisition is the work "Search and Screening" by B.O. Koopman (1946). Koopman

defined *detection* as, "that event constituted by the observer's becoming aware of the presence and possibly of the position and even in some cases of the motion of the target". Listed below are the five levels of target acquisition:

(1) *Cuing information*: Approximate location determined by noise.

(2) *Detection*: Object in field of view.

(3) *Classification*: Observer able to distinguish target.

(4) *Recognition*: Discrimination among finer classes.

(5) *Identification*: Precise identity known. [Ref. 9]

Visual and thermal detection rely solely upon LOS. However, noise from artillery rounds or tank rounds create emanating sound. This emanating sound can give an observer cuing information. With cuing information, an observer can point his optical or thermal sensors in that direction to better enable him to detect the enemy. Cuing information also enables the blue force to fire artillery rounds at the red force before actually seeing them.

Currently, the only widely used algorithm for aural acquisition in a combat simulation model is in UCCATS. The UCCATS algorithm is a combat simulation model designed specifically for Urban Warfare. UCCATS was developed at the Conflict Simulation Laboratory at Lawrence Livermore, California. United States Army Europe (USAREUR), particularly

the Berlin Brigade, was the first major users of UCCATS. Today UCCATS is being used by the Drug Enforcement Agency (DEA) to assist in modeling low intensity conflicts. The DEA and USAREUR can model Urban Warfare and low intensity conflicts at a much reduced cost and can run several different scenarios. UCCATS detects mechanical vehicles based on sound cuing. Sound cuing is based on the distance between the vehicle and the detecting unit. Primarily, UCCATS plays sound which Janus(A) currently does not have available. [Ref. 4]

A possible disadvantage to adding a sound algorithm to Janus(A) is that it will take more computing time and may slow down the combat simulation model. Therefore, as the fourth issue indicated, this thesis will discuss the advantages of utilizing sound versus the additional computing time. A possible solution to enhance the speed of computing should it be slowed down too much by adding a sound algorithm would be to utilize parallel computers.

II. MODEL-TEST-MODEL CONCEPT

A. MODEL-TEST-MODEL PROCESS

As stated in Chapter I, the M-T-M process consists of five phases: long-term planning phase, pretest modeling phase, field test phase, post-test modeling phase, and accreditation phase [Ref. 3:p. I-177].

1. Long Term Planning Phase

This phase begins with all concerned agencies and individuals agreeing to accept various responsibilities in the project. Such responsibilities include working relationships, resource commitments, and products produced by the agencies. Generally this phase is formalized by a Memorandum of Agreement (MOA) specifying the above agreements [Ref. 3:p. I-180].

2. Pretest Modeling Phase

This phase begins the actual modeling process. Essentially, this phase serves as an aid to planners prior to the field testing. Actually, this phase contains two different types of modeling with separate objectives. The first type, product modeling, supports Force Development Test and Evaluation (FDTE). This type, known as pretest FDTE modeling, utilizes maneuver unit leaders and focuses on resolving doctrinal issues of the system to be modelled and

evaluated. Refining the test design is the primary objective of the pretest FDTE. The second type of modeling performed in this phase is the pretest operational modeling. One objective is "to examine whether the test objectives can be met with the proposed test design." [Ref. 3:p. I-181] This thesis deals primarily with this phase, pretest operational modeling, of the M-T-M process. The TUGV will be created and tested on the Janus(A) combat model. This pretest modeling may aid planners in designing a more effective and efficient field test.

3. Field Test Phase

During this phase, the modelers evaluate the system in an actual operating environment. Usually, these modelers are military specialists and experts trained in both the system under evaluation as well as in methods of experimentation. It is critical that the modeler stay involved with the field test to better appreciate the test procedures and data collected. The data collection process then begins. [Ref. 3:p. I-182]

4. Post-Test Modeling Phase

In this phase, the customer determines which measures of performance to use to compare field test data to the model output data. In this phase the modeler adjusts the constructs of the model as required. This adjusting of the model is called the calibration of the model to the test. [Ref. 3:p. I-183]

5. Model Accreditation Phase

This is the final phase of the M-T-M process. In fact, this phase begins the process again and allows for further refinements and improvements. For the modeler, this step can prove to be the most difficult since he or she must prove the credibility of the model. Generally, the agency responsible for the output of the product must accredit the model by stating that the inputs as well as the outputs are, in fact, reliable. [Ref. 3:p. I-184]

B. DESCRIPTION OF JANUS (A)

The simulation modeling tool used in this effort is the Janus(A) Combat Model (version 3.1). The original version of Janus, Janus 1.0, was developed at the Conflict Simulation Center at Lawrence Livermore Laboratory (LLL) (1978-1981) for the purpose of creating a two-sided analytical and training tool to study the modern day battlefield. It was later modified by the Janus working group at the Training and Doctrine Command (TRADOC) Analysis Command (TRAC), 1983, at White Sands Missile Range. Janus is intended for use at brigade-level and below.

Janus(A) is a computer-assisted, opposing-force model, which is a FORTRAN-based wargaming simulation designed for use on a Digital Equipment Corporation (DEC) VAX/VMS computer system. The Janus(A) system is a high-resolution, interactive two-sided, closed, stochastic ground combat simulation model.

"High resolution" refers to the degree of resolution of the modeling of individual systems. "Interactive two sided" refers to the fact that two analysts, representing blue and red, interact with the system as the situation evolves. "Closed" means that each analyst is unaware of the other analyst's moves and actions. "Stochastic" refers to the random means of determining hits and kills. Each hit and kill is determined by preset probabilities of hit and kill (PH/PK). The Janus(A) system models the size and composition of the opposing forces, weather, amount of light, visibility, and chemical environment. In addition, the Janus(A) system will model individual weapons and systems which are part of the forces. From a tactical standpoint, Janus(A) can model engineer support, minefield emplacement and breaching, rotary and fixed-wing aircraft and resupply issues. [Ref. 10, Ref. 11]

Contour lines and varying colors portray terrain, vegetation, and cities in Janus(A). Corresponding to the Defense Mapping Agency elevation, each terrain cell represents a fifty meter resolution. Each graphical symbol depicts one system and each system may have one or several weapons on it. [Ref. 12]

Combat between two systems or forces in the Janus(A) Model is based primarily on LOS. An algorithm exits in Janus(A) to determine the LOS based on the terrain and visibility conditions. The forces currently detect other forces based on

a physical LOS between each other. Since Janus(A) relies solely upon LOS for the detection of two forces, a recommended improvement to TRAC White Sands, New Mexico, who manages Janus(A), is to add a sound algorithm to Janus(A) 3.1, which is the most current edition. The attenuation of sound waves, of course, do not depend upon LOS.

Janus(A) has a comprehensive postprocessing procedure which aids in the collection of data such as detections. The Janus(A) postprocessing procedure will be used in this thesis to collect detection and survivability data between the blue and red forces. This data will then be analyzed to determine the effectiveness of adding the TUGV to the force.

III. TACTICAL UNMANNED GROUND VEHICLE

A. GENERAL

Prior to describing the model, a firm knowledge and understanding of the vehicle or the platform that transports the sensory module is required. This chapter describes in detail the performance characteristics of the platform and the sensory module of the prototype Tactical Unmanned Ground Vehicle (TUGV) as it currently exists. The physical and performance characteristics of such a prototype vehicle are in a state of change due to the nature of designing and developing a new weapon system. Thus, as development continues, some of the data may change or even become obsolete. However, based on the most up-to-date data available, this chapter is a "blueprint" of the actual prototype vehicle to be modeled in the Janus(A) combat simulation model system. Figure 1 on the following page is a photograph of the protoype TUGV and its control panel. Although the vehicle platform has changed to the 4-Wheeled High Mobility Multipurpose Wheeled Vehicle (HMMWV), this is the most up-to-date photo of the proposed design. This photo was included to give a conceptual notion of the TUGV to the reader.

Figure 1 TUGV

B. PLATFORM CHARACTERISTICS

A TUGV system actually consists of two vehicles: a Mobile Base Unit (MBU), which houses the sensory module, and the Operator Control Unit (OCU), in which soldiers remotely operate the MBU. The control panel facilitates the soldiers operating the MBU remotely from the OCU. The MBU and the OCU currently can be separated as far apart as ten kilometers. The soldiers in the OCU command and operate the MBU via secure Frequency Modulation (FM) radio waves. Both the MBU and the OCU use the HMMWV as the basic platform. Table 2 contains the physical characteristics of the platform for the TUGV. The physical properties of the HMMWV will not change. However, the addition of the sensory module to the HMMWV will affect some of the characteristics of the system such as its height, weight, and center of gravity. [Ref. 2]

The Robotic Systems Technology Company, Hampstead, Maryland, developed the original version of the Surrogate Teleoperated Vehicle (STV) which is depicted in Figure 1. This STV was tested from 10 February 1992 to 14 March 1992 at Fort Hunter Liggett, California, which is used as a test range for many new weapons. The test at Fort Hunter Liggett was conducted in accordance with the Test and Evaluation Master Plan (TEMP) using the Concept of Employment Evaluation (COEE). The Project Manager (PM) ordered the test to check the effectiveness of the contractors' prototype. The STV was

found to tip over easily, thereby making it necessary to change the platform to a wider, more stable one. Now the PM has changed the platform to the HMMWV. [Ref. 13]

TABLE 2 TUGV

PHYSICAL PLATFORM CHARACTERISTICS	
Engine	6.2 lt diesel naturally-aspirated, liquid cooled
Transmission	Turbo Hydra-Matic 400 3-speed automatic
Length	457 cm (180")
Width	216 cm (85")
Height (Mast Extended)	430 cm (168")
Height (Mast Not Extended)	216 cm (85")
Weight	3674 kg (8,100 lbs)
Ground Clearance	41 cm (16")
Fording Capabilities	152 cm w/kit & 76 cm w/o
Cruising Range	542 km (337 miles)

C. PERFORMANCE CHARACTERISTICS

1. Platform

Performance characteristics for the Tactical Unmanned Ground Vehicle divide into two categories: the required performance characteristics of the vehicle and the specified performance characteristics of the sensory module. While the platform's features are basically the same as the HMMWV, some alterations are made due to the mission profile and the role of the TUGV. Table 3 lists a summary of the required

performance characteristics of the TUGV platform. [Ref. 14, Ref. 15]

TABLE 3 TUGV PLATFORM

REQUIRED PERFORMANCE CHARACTERISTICS	
Range	400 km (250 Miles)
Endurance	48 hour mission
Maximum Speed	65 kph (40 mph)
Slope Limitations	Front: 35 degrees Side: 25 degrees

2. Sensory Systems

The performance characteristics of the sensory module are divided into three categories: Forward Looking Infrared Radar (FLIR), Day/Night Targeting Camera, and the Acoustic Detection Device. Many of the components of the sensory module are currently under development. Table 4 lists several of the required specifications of the sensory module. [Ref. 16]

The sensory module will also incorporate other components such as Global Positioning System (GPS), a laser range finder/designator, and a Nuclear Biological and Chemical (NBC) detection system. These components, while important to the overall mission success of the TUGV, do not contribute to the enemy detection mission. Additionally, specifications of the mast are included in Table 5. [Ref. 15]

TABLE 4 SENSORY MUDULE

PERFORMANCE CHARACTERISTICS	
Forward Looking Infrared Radar	
Name	IRIS-T AN/TAS-4B
Day Targeting Cameras	
Name	SSC-S20 Sony
Lens	C14X25B-SND 2C-2 Fujinon 14:1 Zoom, 25 to 350mm
Field of View (@ 1/2")	28°30′ x 21°31′
Night Targeting Camera	
Name	SSC-S20 Sony
Lens	C10 x 16A -MD3 10:1 Zoom, 16 to 160mm
Field of View (@ 1/2")	43°36′ x 33°24′
Remarks	Type of camera projected is high resolution, image intensified
Acoustic Detection	
Name	TBA
Detection Range	20 Hz to 25kHz
Remarks	Projected acoustic detection device is binaural audio
Laser Range Finder	
Name	LTM 86 or ESL 100
Detection Range	9995 meters
Chemical Agent Detector	
Name	ICAD
Agents Detected	Nerve, Blister, Blood, Choking

TABLE 5 MAST

MAST SPECIFICATIONS	
Mast height	4.57 m (15 feet)
Turret Motion	+/- 90 degree tilt +/- 270 degree pan
Slew rate	150 to .05 degree per second

This chapter dealt with the prototype Tactical Unmanned Ground Vehicle as the specifications were available. The next chapter's focus is on the specifications of the Janus(A) model TUGV. It is important to first have a good understanding of the object to be modelled, in this case the TUGV, prior to understanding the model.

IV. MODEL OF THE TACTICAL UNMANNED GROUND VEHICLE IN JANUS(A)

A. GENERAL

This chapter will describe in detail the Janus(A) model of the Tactical Unmanned Ground Vehicle. A complete description of the physical and performance characteristics of the platform and sensory module of the TUGV model will be given. As indicated in Chapter III, this data is based on the most current information available, to include facts gathered at the Critical Operational Issues and Criteria (COIC) and Cost and Operational Effectiveness Analysis (COEA) meeting, TRAC White Sands Missile Range (WSMR), New Mexico on 23 February 1993. Also, a description of the probability of hit and the probability of kill is presented in this chapter. Figure 2 on the following page is the icon which represents the TUGV in the Janus(A) model as viewed from the terminal monitor.

B. PHYSICAL CHARACTERISTICS OF THE TUGV MODEL

The following is an explanation of the variables used in the physical dimensions of the TUGV model. The basic dimensions such as the vehicle size, wheel and belly width, engine type, and magnetic shadow width are modelled after the dimensions of the HMMWV; however, the TUGV height in the model is assumed to be four meters. The assumption of a four meter

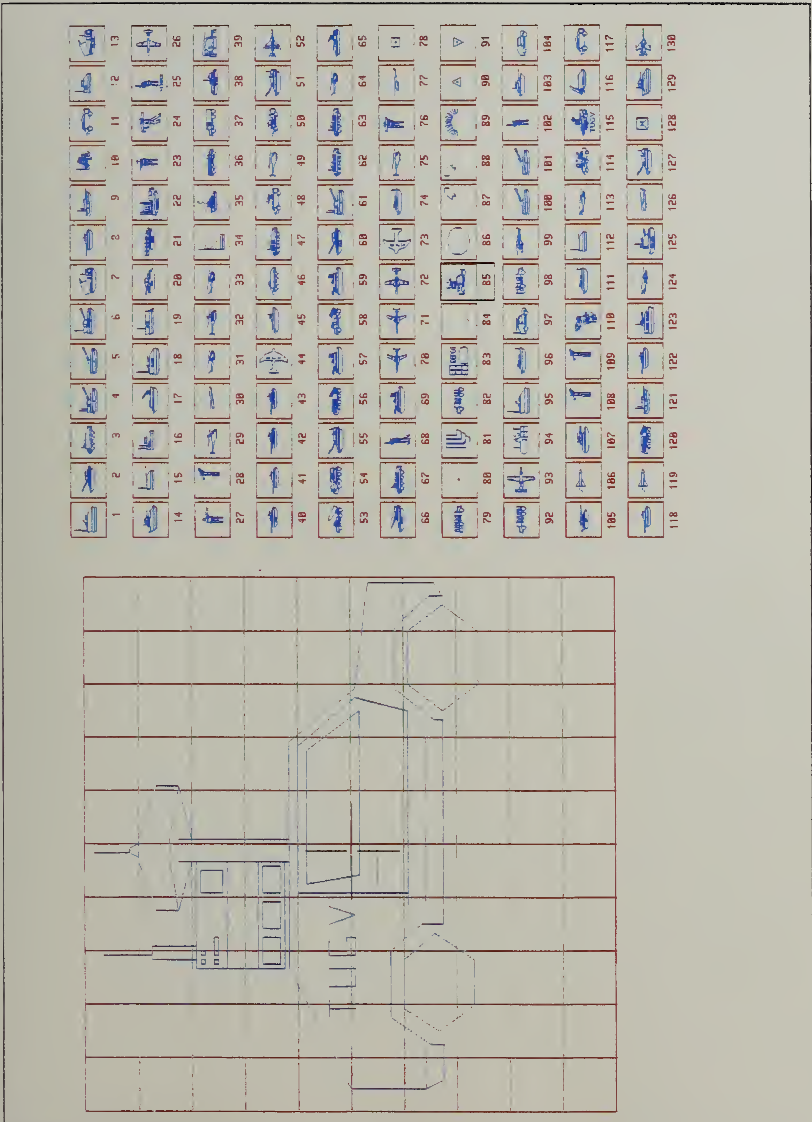

Figure 2 TUGV-Icon

height of the TUGV was required in order to accurately depict the height of the sensory module extended. When the TUGV is in an acquisition mode, the sensory module is elevated to 14 feet above the ground. Thus, by making the height of the TUGV model four meters, this approximates the height of the sensory module when operational. Additionally, minimum detection dimension is assumed to be .2 meters. This assumption is required in order to accurately model the amount of the sensory module exposed to enemy observation and fires. When operational, it is assumed that approximately 80% of the sensory module will be concealed by either natural or manmade camouflage. The sensory platform is approximately one meter in length, thus the assumption is that 20% or .2 meters will be exposed to fire. This also assumes that the vehicle, when operational, is not exposed to enemy observation and fire but rather is in a defilade or concealed posture. Fuel capacity was assumed to be 200 gallons. This was assumed so resupply was not required to be played. The magnetic shadow width, which is the shadow that a ground radar can detect, is assumed to be the same as the HMMWV. Table 6 on the next page lists the physical characteristics of the TUGV which were just described. [Ref. 12]

TABLE 6 TUGV MODEL

PHYSICAL DIMENSIONS OF THE TUGV MODEL	
Vehicle Width	300 cm (118")
Vehicle Height	400 cm (157")
Wheel Width	30 cm (11.8")
Belly Width	245 cm (96.5")
Engine Type	Diesel
Fuel Capacity	200 Gallons
Magnetic Shadow Width	270 cm (106")
Minimum Detection Dimension	20 cm (7.87")

C. PERFORMANCE CHARACTERISTICS OF THE TUGV MODEL

Similar to the physical dimensions of the TUGV, the performance characteristics are modelled, when appropriate, after the HMMWV, or the TUGV prototype. The maximum vehicle speed was assumed to be 25 kilometers per hour (kph) although the specifications on the prototype indicated that is has a maximum speed of 65 kph. This was an attempt to create a more realistic model by hopefully attaining a more reasonable ground speed in the rough and uneven terrain of the actual environment. Table 7 shown on the next page indicates the performance specification inputs to the Janus(A) model of the TUGV. The algorithm which determines movement of this weapon system, TUGV, in the Janus(A) combat model requires the inputs listed in Table 7.

TABLE 7 TUGV MODEL

PERFORMANCE CHARACTERISTICS OF THE TUGV MODEL	
Maximum Speed	25 kph (15.5 mph)
Fuel Consumption:	
Stationary	2 Gallons/hour
Moving	10 Gallons/hour

The representation of the sensory module presented problems in the modelling effort. The current version of Janus(A) only allows a primary and an alternate sensor to be added to a vehicle. The prototype TUGV has three sensors, thermal, optical, and acoustic, operating concurrently and independently. The model described in this thesis has an acoustic sensor which was acquired from the Janus(A) Gaming Division at White Sands, New Mexico. The acoustic sensor can be turned on and off and does not function if the vehicle is in defilade. A more thorough explanation of how the acoustic sensor was developed, the mathematical theory behind its development, and how it actually functions will be elaborated on in the next chapter. Thus, in this model the acoustic sensor functions at all times except as stated above; otherwise, the primary sensor is an optical sight with a thermal sight as the alternate. A point to note is that the acoustic sensor added to this model can work concurrently with

either the optical or thermal sensor. Field of view (FOV) for the thermal sight was established at 5 degree horizontal in the absence of actual data. This FOV was selected because of its common use in other U.S. combat vehicles, such as the M1A2 Abrams Main Battle Tank. The FOV for the optic sight was established at 14.5 degree horizontal to model the day targeting camera of the prototype. Maximum range was established based on the TUGV prototype specifications. Table 8 below lists the specifications of the sensory module of the TUGV model. In order for the Janus(A) combat model to effectively model the sensory capabilities of the TUGV, the inputs of Table 8 are required.

TABLE 8 SENSORY MODULE

SENSORY PLATFORM CHARACTERISTICS OF TUGV MODEL	
Primary Sensor:	
Type	Optical
Field of View	14.5 Degree Horizontal
Alternate Sensor:	
Type	Thermal
Field of View	5 Degree Horizontal
Maximum Range of Sensors	2000 Meters
Laser Designator	Included in sensory module
Acoustic Sensor	Included in sensory module

The specifications of the thermal sight and the optical sight used on the TUGV are listed in Tables 9 and 10. These specifications match existing sights in Janus(A) and are the ones chosen since no specific requirements were given.

TABLE 9 OPTICAL SIGHT

OPTICAL SIGHT SPECIFICATIONS FOR TUGV MODEL	
Narrow Field of View	6.5 Degrees
Wide Field of View	6.5 Degrees
CYCLES PER MILLIRADIAN (Search Sector)	CONTRAST DIFFERENCE FOR DETECTION
0	.02
1.75	.027
9.75	.077
11.75	.268
21.17	1.000

TABLE 10 THERMAL SIGHT

THERMAL SIGHT SPECIFICATIONS FOR TUGV MODEL	
Narrow Field of View	5.0 Degrees
Wide Field of View	5.0 Degrees
CYCLES PER MILLIRADIAN (Search Sector)	TEMPERATURE DIFFERENCE FOR DETECTION
0	.01
1.225	.075
2.175	.171
3.725	.330
5.0	1.12

The probability of hit and the probability of kill (PH/PK) against the model TUGV presented somewhat of a problem. While the HMMWV has established PH's and PK's, the TUGV prototype originally did not. Therefore, the PH/PK for the TUGV were assumed to be 1/10 that of the HMMWV; which is equivalent to the HMMWV in defilade. The authors of the thesis made this assumption and is considered valid because only a surface area of approximately 10% of the sensory module would be exposed to enemy fire due to natural and man-made camouflage. The PH and PK for this model is the same because it is assumed that if the sensory module or platform gets hit it gets killed since it has no protection and is extremely susceptible to damage from munitions. In the scenarios developed by the Test and Evaluation Command (TEC), Fort Hunter Liggett, and used in this thesis to test the TUGV's effectiveness in Janus(A), three former Soviet weapon systems can engage and kill the TUGV. These weapon systems are the short-range, tube-launched disposable infantry antitank grenade launcher known as the RPG-18, the wire-guided antitank guided missile system (SPANDREL), called the AT-P-S, and the 30mm Armor-Piercing Defensive System (APDS) mounted on Soviet light armored personnel carriers or better known as the *Avtomaticheskiy Granatomyot Stankoviy* (Automatic Grenade Launcher). Table 11 on page 31 is an example of the PH/PK's for these weapon systems, reduced by 90%. The exact data cannot be listed in the thesis since it is classified to mention the name of the

weapon system and give its PH/PK table together. The PH/PK tables for these weapon systems can be obtained from TRAC Monterey. Also, as stated on the previous page the tables were reduced by 90% before placing them into the model due to the assumption the authors made in reference to the TUGV in defilade. These tables use abbreviations in the heading of each column such as SSDF which must first be explained. In using these abbreviations the first letter stands for the posture of the target (S: stationary, M: moving), the second letter represents the posture of the firer (S/M), the third letter depicts the exposure of the target (D: defilade, E: exposed), and the fourth letter indicates the location of the hit (F: flank, H: Hull). The ranges, of each table, are the ranges for the probability hit of the HMMWV.

TABLE 11 EXAMPLE PH/PK TABLE

EXAMPLE OF PROBABILITY OF HIT AND KILL OF A SOVIET BUILT WEAPON AGAINST THE TUGV (INCLUDING A 90% REDUCTION)								
RANGE (Km)	SSEF	SSEH	SSEF	SSEH	SMDF	SMDH	SMEF	SMEH
.005	.155	.145	.130	.195	.125	.146	.023	.012
.400	.124	.167	.149	.154	.122	.023	.041	.050
.800	.110	.100	.040	.020	.010	.075	.037	.019
1.600	.189	.145	.028	.045	.014	.012	.020	.020
2.800	.112	.111	.010	.012	.011	.001	.010	.001
	MSDF	MSDH	MSEF	MSEH	MMDF	MMDH	MMEF	MMEH
.005	.135	.118	.150	.160	.033	.018	.090	.060
.400	.121	.112	.139	.144	.081	.052	.040	.074
.800	.120	.145	.180	.029	.010	.015	.090	.038
1.600	.112	.131	.143	.100	.002	.001	.002	.007
2.800	.111	.120	.097	.046	.021	.070	.007	.005

V. ANALYSIS OF AN ACOUSTIC DIMENSION FOR JANUS(A)

A. GENERAL

This chapter deals directly with the acoustics aspects of the sensory module of the Tactical Unmanned Ground Vehicle. The chapter begins with an introduction of sound, how it propagates and various factors that can affect its propagation. Following the introduction a section will be devoted to the current sound algorithm that exists on the TUGV modelled in this thesis. This is the only acoustic algorithm that exists on a mobile vehicle in any Janus(A) model. The authors of this thesis acquired this sound algorithm from TRAC White Sands, New Mexico, February 1993 and incorporated it into their model at TRAC Monterey. An analysis of the theoretical development of the current sound algorithm will be given followed by a brief description of the actual FORTRAN coded algorithm. Finally, the chapter will conclude by looking at the acoustic algorithms in two other models which currently utilize sound, UCCATS and BNOISE, and how parts of these algorithms may be used to improve the current sound algorithm on the TUGV. The temperature inversion subroutine in BNOISE is of particular importance since it could be used to improve the current sound algorithm on the TUGV described in this thesis.

B. BASIC PROPERTIES OF SOUND

1. Theory

This section describes only the basic properties of sound to give a general understanding of the properties of sound and how it propagates. The section will conclude by discussing factors that can effect the speed of sound in the atmosphere.

Sound is a form of energy and can best be described as a wave phenomenon. Each small particle of air vibrates in some pattern and passes on the effects to its bordering neighbors. In air the vibration is always parallel to the direction of wave travel; therefore, sound waves are called longitudinal waves. These vibrations are registered in cycles per second (c/s) or hertz (Hz) in which the human ear has a range of 20 Hz to about 20,000 Hz. This range is referred to as the audible range. The basic property for producing sound is that the source must generate some form of vibration. [Ref. 17:p. 3]

The speed of sound is how fast a particular signal goes from one location to another and frequency is how often the oscillating motion repeats at a single place. Speed is measured in meters per second (m/s), while frequency is measured in c/s or Hz. In the audible range, frequency varies from 20 Hz to 20,000 Hz. The period of a vibration is the time from which the vibrating point passes through any

position until it passes through the same position moving in the same direction and is symbolized as T. The frequency is the reciprocal of the time period and is denoted as

$$f = \frac{1}{T}. \tag{1}$$

The amplitude, A, of the vibration is the maximum displacement of the vibrating particle during the course of its motion from its mean position. The wavelength is the crest-to-crest distance in the direction of wave travel. Speed or velocity (v), frequency (f), and wavelength (λ) are related by

$$v = f \times \lambda. \tag{2}$$

Finally, in the most general of terms sound waves behave in a sinusoidal motion. Although, many other factors such as weather and terrain alter sound wave transmissions in the air, the waves still remain somewhat similar to a sine wave. [Ref. 17:p. 4]

A common way to determine the strength of a sound wave is by the amount of energy is carries. To estimate the amount of energy the rate of emission or power P is determined by

$$P = \frac{dE}{dt} \tag{3}$$

where E is a measure of total energy over all time. Therefore, by taking the derivative of E with respect to time one gets the rate of emission or power. [Ref. 17:p. 6]

Since a large range of sound-wave amplitudes are encountered, a common way to represent their strength is on a logarithmic scale called sound level. Used in this thesis is a logarithmic scale called the sound pressure level:

$$SPL(dB) = 20\log_{10}\left(\frac{p}{p_{ref}}\right), \tag{4}$$

where dB represents decibels, p is the amplitude of the wave in Pascals(Pa), and p_{ref} is a reference standard. For air p_{ref} is near 20 micropascals or 2×10^{-5} Pa. The factor 20 is required to standardize the equation. The reference standard p_{ref} varies in different media; therefore, creating a method to compare the same sound level but in varying media. [Ref. 17:p. 8]

2. Meteorological Effects

Now, a general discussion of how pressure, temperatûre, humidity, and wind affects the velocity of sound will be given. In general the velocity of sound can be determined by

$$v = \sqrt{\frac{\gamma P}{\rho}}, \tag{5}$$

where γ is the ratio of specific heats which is constant depending upon the medium, P is the pressure and ρ is the density of the medium; in this case the medium is air, γ is approximately 1.402, and ρ is near 1.2 depending upon temperature and pressure. For air at sea level the velocity

turns out to be approximately 330 meters/second (m/s). [Ref. 18:p. 124]

a. *Effects of Pressure*

Say the temperature of air which only affects the density of varying media remains constant then a change of pressure will not affect the velocity of sound. This can be seen using (5). In reference to Boyle's law $P\upsilon$ = constant, where P is the Pressure and υ is the volume. Therefore, if pressure is changed to P′ then the density of air changes to ρ' so the new velocity v′ is given by

$$v' = \sqrt{\frac{\gamma P'}{\rho'}}. \tag{6}$$

Then dividing by the initial velocity and using Boyle's Law one gets

$$\frac{v'}{v} = \sqrt{\frac{P'\rho'}{P\rho'}} \Rightarrow \text{By Boyle's Law } \frac{P}{\rho} = \frac{P'}{\rho'} \Rightarrow v = v'. \tag{7}$$

Therefore, relating this back to the TUGV a pressure change within the environment will not affect the speed or amount of sound waves that the acoustic sensor will detect. A high or low pressure system will have no impact on the TUGV's acoustics system. [Ref. 18:p. 124]

b. *Effects of Temperature*

The density of air changes with varying temperatures causing the velocity of sound to change. Assume

pressure remains constant and let v_o denote velocity at 0° celsius (C) and v_t denote velocity at t° C. Then,

$$\frac{v_t}{v_o} = \sqrt{\frac{\rho_o}{\rho_t}} \tag{8}$$

where ρ_o and ρ_t are the densities of air at 0° C and t° C. Now let α = 1/273 be the coefficient of expansion which is used to relate temperatures recorded in celsius to Kelvin. The equation $(1 + \alpha t)$ represents the factor of increase due to temperature increase in celsius. Now,

$$\rho_o = \rho_t(1 + \alpha t) \tag{9}$$

and dividing by initial velocity one gets

$$\frac{v_t}{v_o} = \sqrt{1 + \alpha t} \Rightarrow \frac{v_t}{v_o} = \sqrt{\frac{273 + t}{273}} = \sqrt{\frac{T_t}{T_o}}. \tag{10}$$

Therefore, the velocity of sound in air is directly proportional to the square root of the absolute temperature. BNOISE sound algorithm does take into account temperature inversion and how it affects the speed of sound. Section D of this chapter will describe in detail the temperature inversion subroutine of BNOISE and how it may be applied to the current sound algorithm in this thesis. [Ref. 18:p. 125]

c. Effects of Humidity

Moisture in the air lowers its density causing an increase in velocity through it. The greater the humidity, the higher the degree of moisture content, resulting in an

increased velocity in sound wave propagation. For instance, let v_d denote the velocity of sound in dry air at temperature t and let v_m represent the velocity of sound at same temperature but different moisture content. Now let ρ_m be the density of moist air and ρ_d be density of dry air then

$$\frac{v_d}{v_m} = \sqrt{\frac{\rho_m}{\rho_d}} \Rightarrow v_m = \frac{v_d}{\sqrt{\frac{\rho_m}{\rho_d}}}. \tag{11}$$

Since $\rho_m < \rho_d$ (11) ensures that $v_m > v_d$. [Ref. 18:p. 125] The effects of humidity is one area that could be further developed and incorporated into the current sound algorithm. However, this thesis will not go any further in discussing the effects of humidity.

d. Effects of Wind

The velocity of sound waves in the air are directly affected by the wind. For example, if the wind blows at a velocity of w in the direction of sound then the resultant velocity of sound, v, will be cumulative (v + w). If wind blows 180° opposite the direction of the sound wave propagation, then the resultant velocity will be (v - w). Finally, if the wind blows at an angle θ with the direction of sound propagation then the resultant velocity will be (v + w cos θ) or (v - w cos θ). [Ref. 18:p. 126]

The current sound algorithm used on the TUGV's sensory module modeled in this thesis incorporates the effects

of upwind, downwind, and neutral wind. The current sound algorithm will be discussed in detail in section C of this chapter.

These are the only meteorological effects that this thesis will discuss. As stated, pressure changes do not affect the speed of sound. The changes in temperature, humidity, and wind do affect the speed of sound. Weather conditions to include humidity are altered in Chapter VI. The effect of changing only humidity is not analyzed in this thesis. An analysis is done in Chapter VI encompassing the effects of altering several factors in weather at one time. On the other hand, this thesis will analyze theoretically the effects of temperature inversion and wind. Particularly with temperature inversion a subroutine on BNOISE will be analyzed. Many other factors such as terrain and vegetation affect the propagation of sound waves; nevertheless, this thesis does not elaborate on these factors.

3. Assumptions

For purposes of this thesis the following assumptions were made concerning sound:

(1) The propagation of sound is modeled as a wave front that expands in a spherical manner from the source.

(2) Sound has no blind spots.

(3) Friendly forces can only hear enemy forces.

(4) Each platform is considered in isolation.

These are the general assumptions made for the current sound algorithm which is used with the TUGV. Additional assumptions will be listed in the following sections dealing with each particular algorithm. Since a sound algorithm does not rely upon LOS as do optical and thermal (heat sensitive) sights, an acoustic cuing model can be beneficial to target acquisition. Once an enemy vehicle or aircraft has been detected acoustically, the other sensors' field of views can be adjusted or the friendly forces can be moved to another location in order to detect with their optical or thermal sights. In essence, the acoustic sensor is an excellent cuing device to help the operator of the TUGV to focus his other sensors once an enemy is detected acoustically.

C. EXISTING SOUND ALGORITHM ON TUGV

This section is subdivided into two sections. The first subsection deals with the theoretical analysis of the sound algorithm that the authors of this thesis acquired at TRAC White Sands. The supporting documentation for the theoretical analysis was obtained from Lieutenant Colonel (LTC) John Robertson at the United States Military Academy (USMA) Department of Mathematical Sciences. LTC Robertson conducted the initial theoretical analysis of this sound algorithm for the Director of the Signature Sensors and Signal Processing Technology Office (S3TO) at the U.S. Army Laboratory Command (LABCOM), Aldelphi, Maryland. The Director of S3TO then sent

the necessary information to TRAC White Sands who in turn developed a sound algorithm. The sound algorithm itself will be discussed in the second subsection of this chapter. Mr. Barney Watson at TRAC White Sands designed the initial sound algorithm that was coded for Janus(A). As of today this sound algorithm is only available on a limited basis at TRAC White Sands and at TRAC Monterey upon request. The advantage of the TUGV model over the model at White Sands is that the TUGV is mobile as opposed to the White Sands model which was stationary.

1. Theoretical Analysis of Current Sound Algorithm

As stated earlier this analysis was originally done by LTC Robertson for the S3TO at U.S. Army LABCOM. This theoretical analysis provides a general concept of the basic data and where it came from for the current acoustic algorithm. The sound algorithm itself only detects track vehicles, wheel vehicles, and aircraft from the opposing force. The detection distances differ depending upon whether or not the receiver is upwind, downwind, or if there is no wind (neutral wind). Therefore, the sound algorithm takes the effects of wind into account. The algorithm also takes ground impedance into account. Basically, ground impedance occurs because the ground acts as a reacting surface for the reflection of sound waves such that, for any frequency, the ratio of complex pressure amplitude to the into-ground

component velocity amplitude, v_z, is independent of the direction of the incident wave. The ratio is the specific

$$Z = \frac{\rho}{-v_z} \tag{12}$$

acoustic impedance of the ground and usually decreases monotonically with an increasing frequency. [Ref. 19:p. 85] U.S. Army LABCOM provided LTC Robertson with a graphs of Ambient Noise level, the noise that prevails after all easily distinguishable sound sources are deleted [Ref. 19:p. 297], and the Spectral Analysis for M1 Abram tank idle and moving at 20 mph, M60 tank idle and moving at 20 mph, and UH1 helicopter. All of these graphs assumed a ground impedance of 100 $cm^3gm^{-1}s^{-2}$. Therefore, this analysis takes into account wind speed and direction, ground impedance, and ambient noise level. This subsection will demonstrate how the detection distances were determined. Only one specific example will be covered in this subsection. Moreover, the remaining available data is provided in Appendix A. [Ref. 20]

The following derivation will describe the probability of identifying an M60 tank at idle with the receiver being neutral (no wind), downwind, and upwind. To understand the derivation the following terms are defined [Ref. 20,Ref. 21]:

- f: designated frequency
- L: length
- N: total number of channels

- β: bandwidth of filter
- $\bar{t}_{fa}$: average false alarm time
- TL: transmission loss at *f* for target at range r
- SL: target source level at *f*
- NL: ambient noise level in 1-Hz band at *f*
- σ_g: ground impedance
- FFT: fast fourier transform
- P_{id}: probability identification
- P_d: probability detection
- DT_{Hz}: narrowband detection threshold
- dB: decibel level
- d: signal-to-noise ratio at the input to the envelope detector
- SPL: sound pressure level in dB

For this sound algorithm model the following assumptions for propagation, detection, and identification were made.

Propagation:

(1) The source transmits sound in all directions.

(2) The sensory module on the TUGV receives sound in all directions.

(3) The atmosphere is isothermal.

(4) The wind speed is approximately 6 knots.

(5) The three states of neutral, downwind, and upwind are considered in computing propagation distances.

(6) Source speed has no impact on the sound speed (source speed << sound speed).

(7) Ground impedance, σ_g, is 100 $cm^3gm^{-1}s^{-2}$.

(8) The frequency of 100 Hz is used in the calculations and graphs for 10 Hz and 50 Hz are available in Appendix A.

(9) All probability calculations are done using the NASA implicit finite difference (NIFD) model.

<u>Detection:</u>

(1) *Spatial Filter*, sensory system performs this function, is a two-point line array with L = 10'.

(2) *Predetection Processor*, bank of contiguous <u>narrowband filters</u> using FFT with β = .5-Hz covering a 180-Hz band centered at 100 Hz.

(3) *Postdetection Processor*, linear lntegrators with T = 5 sec.

(4) Desired system $\bar{t}_{fA}$: 60 sec.

<u>Identification:</u>

(1) $P_{id} = .8(P_d)$

(2) *Source Strength correction*: It is assumed all measurements were taken at 31 m. The true source level at 1 m (assuming spherical spreading of sound waves)is 20log(31) - 20log(1) = 30 dB. therefore, to predict the TL, a 30 dB correction needs to be added to the source strength, (SL). [Ref. 20]

As stated previously the M60 tank at idle will be utilized in this subsection to derive its acoustic detection distances with neutral wind, downwind, and upwind conditions for the receiver. The P_d and P_{id} at 90%, 50%, and 10% will be calculated. The calculations will be done at *f* = 100 Hz for this derivation.

STEP 1: Calculate the source level at 100 Hz by referring to Figure 3 below, the spectral analysis for the M60 tank at idle to one micropascal, and take the highest point at 100 Hz which is 105 dB. Now add 30 dB, source strength correction, to 105 dB to get a total of 135 dB at 100 Hz.

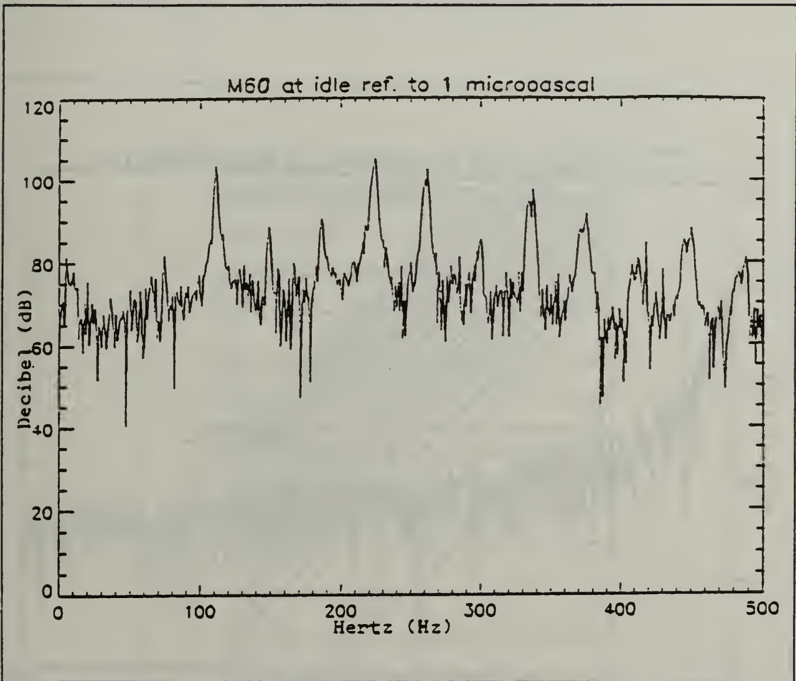

Figure 3 Spectral Analysis M60 Tank at Idle

STEP 2: Determine the ambient noise level (NL) by referring to Figure 4 below, Ambient Noise referenced to one microPascal graph. Take 100 Hz on the horizontal axis go up to the smoothed line then go horizontally to the vertical axis and get approximately 43 dB. The smoothed line was used because it gives an average value over a period of time.

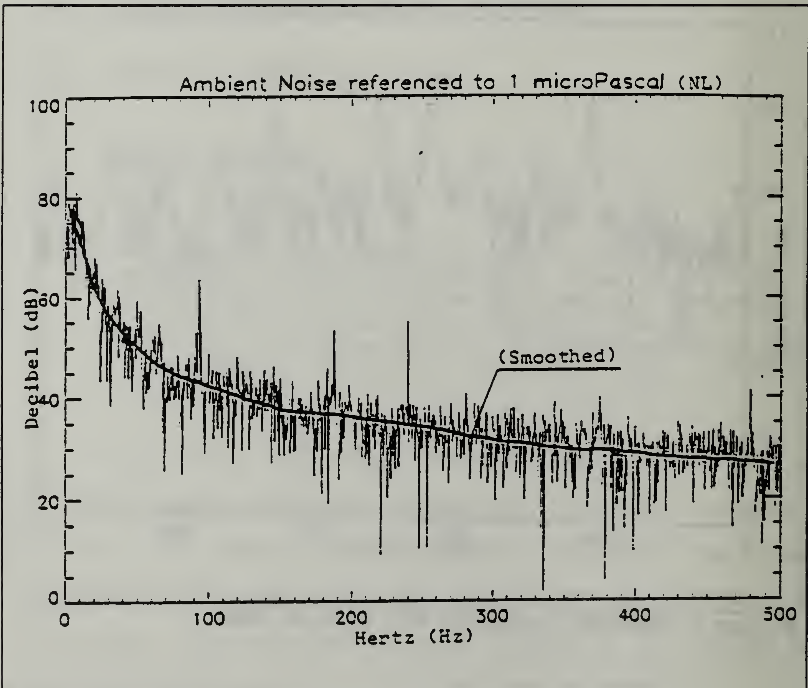

Figure 4 Ambient Noise

STEP 3: Compute the probability of False Alarm (P_{fA}) to determine the signal-to-noise ratio (d), which is

$$P_{fA} = \frac{T}{Nt_{fA}} = \frac{5}{(180)(60)} \approx 5 \times 10^{-4}. \qquad (13)$$

To determine d refer to Figure 5. Go to 5×10^{-4} on the horizontal axis and go up to P_d of 10%, 50%, and 90% to get d's of roughly 6, 12, and 23 respectively.

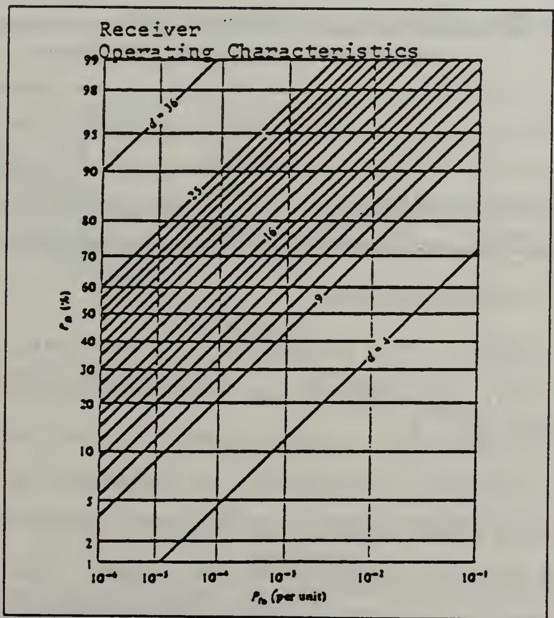

Figure 5 ROC Curves

Now the narrowband detection threshold must be calculated by using the following equation:

$$DT_{Hz}(dB) = 5\log_{10}d - 5\log_{10}\frac{T}{\beta}. \tag{14}$$

This equation corresponds to the required ratio to *total* signal power to noise power *per hertz* at the input to the envelope detector [Ref. 21:p 413]. Table 12 below summarizes the narrowband detection threshold for P_d's of 90%, 50% and 10%.

TABLE 12 DT_{Hz} (dB)

NARROWBAND DETECTION THRESHOLD				
P_d(%)	d	$5\log_{10}d$	$5\log_{10}T/\beta$	DT_{Hz}(dB)
90%	23	6.801	5	1.801
50%	12	5.396	5	.396
10%	6	3.891	5	-1.101

<u>STEP 4</u>: The final step to determining the P_d's and P_{id}'s at 90%, 50%, and 10% use Figure 6, Range versus Sound Pressure Level (SPL) graph, located on the following page. These curves were developed by LTC Robertson at West Point. The neutral wind, upwind, and downwind curves have all been smoothed and are indicated on the graph. The mathematical program written by LTC Robertson to develop these curves takes several factors into consideration beyond the scope of this

thesis. However, basically given a particular SPL one can determine the distance at which sound can be detected given the wind condition and the hertz. Before utilizing the graph, Range versus SPL, the TL's at 100 Hz for target at range 31 m must be determined at 90%, 50% and 10%. One must use TL since it corresponds to the SPL on the SPL versus Range graph of Figure 6. The formula for calculating the TL's is

$$TL = SL - NL - DT_{Hz}. \tag{15}$$

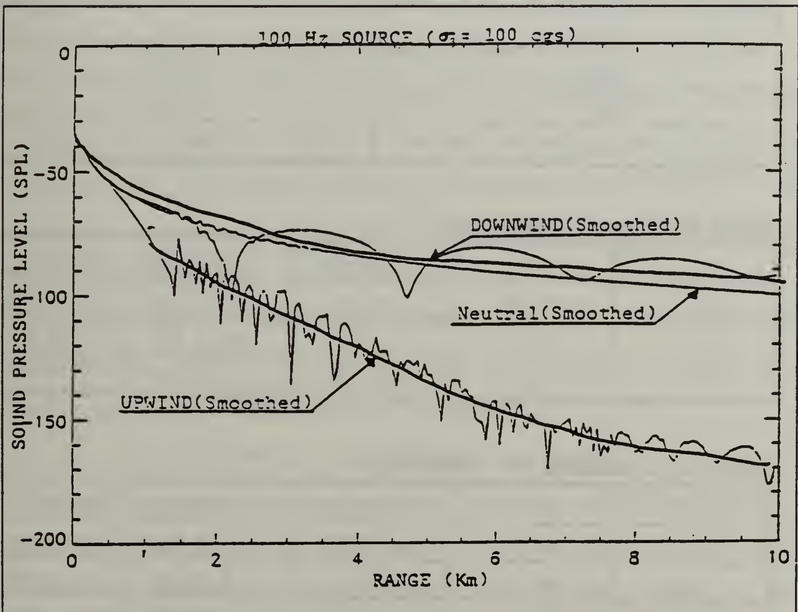

Figure 6 SPL Versus Range (100 Hz)

Table 13 summarizes the TL's for 90%, 50%, and 10% for this derivation. In order to determine the distances that an M60 tank at idle can be detected can now be estimated by utilizing the TL's and Figure 6. The TL corresponds to the SPL on the SPL versus Range graph of Figure 6. For instance at P_d = 90%, TL = 90.2 and using 100 Hz source one gets approximately a range of 1.6 Km for receiver being upwind. Table 14 summarizes the results for P_d of M60 tank at idle at 100 Hz and Table 15 takes 80% of Table 16 to get the P_{id}'s. [Ref. 20]

TABLE 13 TRANSMISSION LOSS

P_d	TL
90%	90.2
50%	91.6
10%	93.1

TABLE 14 RANGE DETECTIONS

P_d	TL	NEUTRAL	DOWNWIND	UPWIND
90%	90.2	5.9 Km	8.0 Km	1.6 Km
50%	91.6	7.0 Km	10.0 Km	1.8 Km
10%	93.1	8.5 Km	12.0 Km	1.9 Km

TABLE 15 DISTANCE TO IDENTIFY

P_{id}	TL	NEUTRAL	DOWNWIND	UPWIND
90%	90.2	4.7 Km	6.4 Km	1.3 Km
50%	91.6	5.6 Km	8.0 Km	1.4 Km
10%	93.1	6.8 Km	9.6 Km	1.5 Km

This summarizes the theoretical analysis which supports the acoustic sound algorithm currently emplaced on the TUGV which the authors of this thesis created. The theoretical analysis only discussed the M60 tank at idle; however, additional data has been included in Appendix A for the M1 Abrams tank idle and moving at 20 mph, M60 tank moving at 20 mph, and the UH1 helicopter. No theoretical analysis was done on a wheeled vehicle in the thesis. The following subsection discusses the actual FORTRAN code emplaced in the Janus(A) code to make the sound algorithm function on the TUGV.

2. Acoustic Detection Subroutine

The subroutine, ACOUSDET2, was developed at TRAC White Sands, New Mexico, by Mr. Barney Watson. Mr. Watson was conducting stationary acoustic testing for the U.S. Army LABCOM. During a trip to TRAC White Sands in February 1993 the authors of this thesis acquired this sound algorithm and incorporated it into the TUGV model at TRAC Monterey. Therefore, TRAC Monterey has the only mobile vehicle which has a sound algorithm on it in Janus(A).

The subroutine, ACOUSDET2, is listed in Appendix B. The subroutine determines which targets are detected by the acoustic sensor on the TUGV model. Targets within a specified area (15 degrees for this model) of another target already detected are regarded as the same target. Table 16 indicates

the original data provided to TRAC White Sands for detection distances of tracked and wheeled vehicles.

TABLE 16 ORIGINAL DATA

DETECTION DISTANCES	
VEHICLE TYPE/ VEHICLE STATUS/ WIND CONDITION	DISTANCE (Km)
Wheeled, Stat, UpWind	1.3
Wheeled, Stat, Downwind	6.4
Wheeled, Stat, Neutral	4.7
Wheeled, Moving, Upwind	1.3
Wheeled, Moving, Downwind	6.4
Wheeled, Moving, Neutral	4.7
Tracked, Stat, Upwind	1.3
Tracked, Stat, Downwind	6.4
Tracked, Stat, Neutral	4.7
Tracked, Moving, Upwind	1.3
Tracked, Moving, Downwind	6.4
Tracked, Moving, Neutral	4.7

No specific data was given to TRAC White Sands concerning the detection distances for wheeled vehicles; therefore, an assumption was made by Mr. Watson to take 30% of the track vehicles detection distances. To compensate for LOS being obscured from terrain the data was reduced another 30%. Since sound is not actually dependent upon LOS this reduction of 30% is an assumed method of dealing with the effects vegetation

and varying terrain has on sound waves. Vegetation and terrain will reduce the distance sound waves travel; hence, a 30% reduction is an estimate. Table 17 below shows the obscured and non-obscured detection distances actually used in this acoustic algorithm. [Ref. 22]

TABLE 17 DISTANCES IN ALGORITHM

DETECTION DISTANCES USED IN ACOUSDET2		
VEHICLE/ VEHICLE STATUS/ WIND	NON-OBSCURED DISTANCE (Km)	OBSCURED DISTANCE (Km)
Wheel\Stat\Upwind	.39	.273
Wheel\Stat\Downwind	1.92	1.344
Wheel\Stat\Neutral	1.41	4.48
Wheel\Mov\Upwind	.39	.273
Wheel\Mov\Downwind	1.92	1.344
Wheel\Mov\Neutral	1.41	3.29
Track\Stat\Upwind	1.3	.91
Track\Stat\Downwind	6.4	4.48
Track\Stat\Neutral	4.7	3.29
Track\Mov\Upwind	1.3	.91
Track\Mov\Downwind	6.4	4.48
Track\Mov\Neutral	4.7	3.29
Helo\Stat\Upwind	1.8	1.8
Helo\Stat\Downwind	8.8	1.8
Helo\Stat\Neutral	8.0	1.0
Helo\Mov\Upwind	8.8	1.8
Helo\Mov\Downwind	8.8	8.8
Helo\Mov\Neutral	8.0	8.0

The algorithm is designed only to detect vehicles from the opposing force. Once a target is detected a directional line will be displayed. The direction incorporates the circular error probability (CEP). Once the TUGV detects an enemy wheeled vehicle, tracked vehicle, or helicopter acoustically a colored line will emanate from the TUGV in the general direction of the enemy target. The line color and length represent the highest priority target in the set. The priority from lowest to highest is wheeled (orange/red line), tracked (purple line), and helicopters (green line). If a target is detected by two or more acoustic sensors an "A" will be displayed on the monitor at the intersection of the lines to indicate an exact location of the target with a small degree of error. Figure 7 on the following page shows an example of the TUGV's acoustic sensor functioning on the current model. Each acoustic sensor can detect up to 100 different targets at one time. The sensor does not function while the TUGV is moving or in holdfire status. The TUGV's acoustic sensor not functioning while the TUGV is moving is more realistic because during movement the only noise the sensor would probably detect is the TUGV's. The holdfire button is just a method to turn the acoustic sensor on and off. The screen display is updated every 30 seconds. The four factors which were used in Table 17 to determine the range at which an acoustic sensor can detect a target are: wind direction, vehicle type, movement status, and LOS.

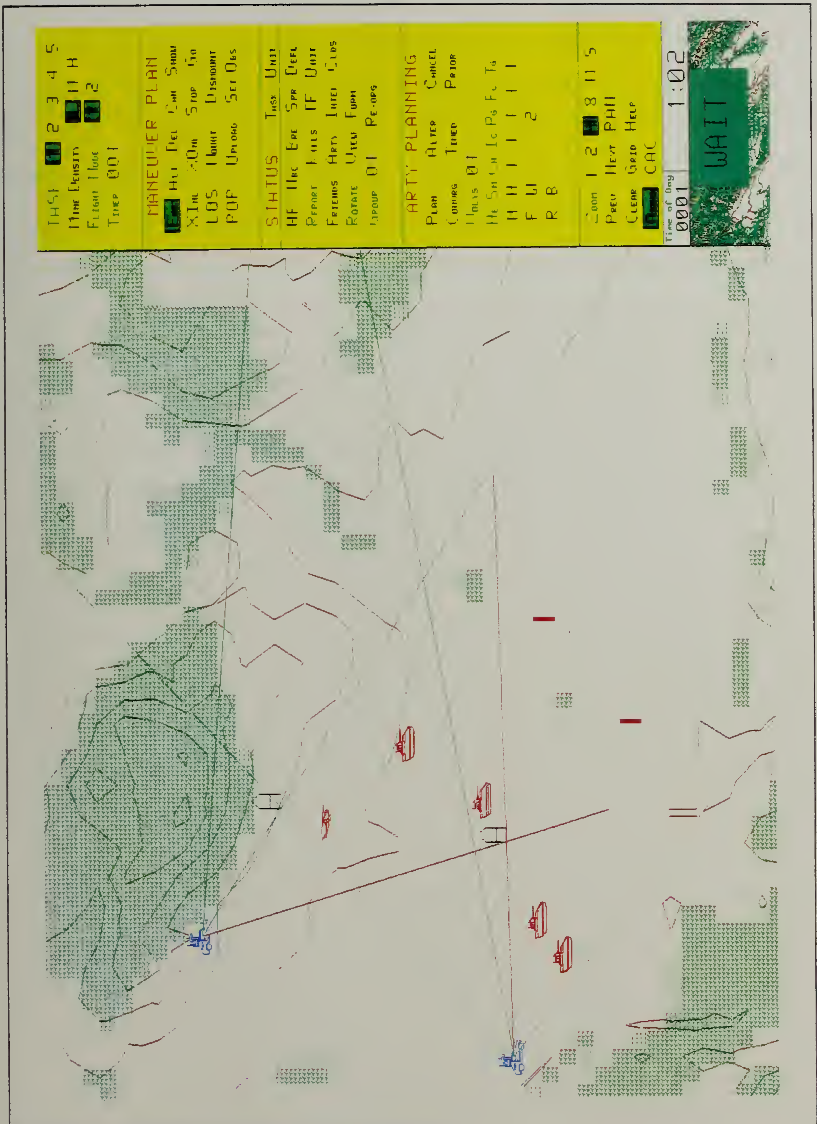

Figure 7 Example Acoustic Sensors

Therefore, this algorithm takes into account the atmospheric condition of wind and assumes a reduction of 30% for vegetation and varying terrain (when LOS is hindered). A recommended improvement to Janus(A) which would make this algorithm more flexible would be to add an acoustic data input screen. The user could manually input using the acoustic data input screen the reduction rate for vegetation\terrain and the degree of separation at which one target must be from another to be distinguished as a separate target. This acoustic algorithm that the authors acquired at TRAC WSMR did not take any significant more computing time while conducting the combat simulation. Therefore, since this algorithm shows no signs of slowing down the simulation, it appears to be advantageous to include it in the Janus(A) system with the above recommended improvements. As indicated in Chapter I, should the simulation be slowed down by adding several TUGV's with acoustic sensors, parallel computers could be utilized to speed up the computing. The concept of parallel computing will not be discussed any further in this thesis. An entirely new thesis could be done analyzing the concept of incorporating parallel computing in Janus(A). The next section will propose an improvement to the existing acoustic algorithm by taking into account temperature inversion. [Ref. 22]

D. ANALYSIS OF OTHER SOUND ALGORITHMS

Two other known computerized models utilize a sound algorithm. The Urban Combat Computer Assisted Training System (UCCATS) is used for military combat training. BNOISE was developed by the U.S. Army Construction Engineering Research Laboratory (USA-CERL) to predict the amount of noise that noise-sensitive areas such as off post housing receive from ranges on post. BNOISE takes into account temperature inversion when calculating the SPL. This temperature inversion subroutine in BNOISE will be the main focus of this subsection. A brief description of BNOISE will be given then a detailed analysis of its temperature inversion subroutine will de discussed. The section will conclude with a brief explanation of UCCATS since it is currently the only combat simulation model with sound being used in the Army.

1. BNOISE

BNOISE is a series of computer programs that together produce a C-weighted day/night average sound level (CDNL) contours for military installations which receive noise from on post ranges. The CDNLs are empirical data existing within the BNOISE data base. The empirical data supporting BNOISE was gathered by the USA-CERL at Fort Leonard Wood, Missouri. The USA-CERL acquired data from various noise sources concerning their sound propagation. USA-CERL studies consists of measurements of the propagation of 735 five-pound charges

set off at Fort Leonard Wood which examined the weight relation between blast charge size and blast amplitude and duration. This data provides the basis for the program BNOISE to predict the noise impact on military installations from ranges. The programs are written in FORTRAN 77 and can be used on any IBM personal computer [Ref. 5:p. 7, Ref. 23:p. 9].

The subroutine, TABGEN, in BNOISE will be the only section of the program elaborated upon since it is the only section that deals with temperature inversion. Temperature inversion represents varying temperatures within the atmosphere. Layers within the atmosphere may have different temperatures and this directly affects the way sound propagates through the atmosphere. TABGEN generates a table of noise levels as a function of distances and temperature inversion factors from the standard five-pound C-4 (demolition) charges. The user of the program inputs the appropriate inversion data for the location of interest. The temperature inversion tables are available from the National Weather Service and they summarize observations made at selected weather stations. A copy is provided in Appendix C. For the purposes of this thesis the analysis of TABGEN will focus on the theoretical aspect of the subroutine. The code is available for reference in Appendix C and copies of the entire program are procurable from USA-CERL by requesting Technical Report N-86/12, June 1986, with disks. [Ref. 5:p. 19.1-21]

Diurnal variations in meteorological aspects are caused by the sun heating the air. The sun's heating and the reaction with the ground causes what is known as inversion layers to occur in the air. During the day the ground absorbs the sun's heat, then the air near the surface is heated by conduction. At night, the ground's outward radiation exceeds the incoming radiation causing temperature inversions that increase with height. These inversion layers cause sound to increase in intensity at large distances from the source and this phenomenon is known as sound energy focusing. [Ref. 23:p. 56-57]

The basic principle behind TABGEN includes standard percent/temperature inversion factors. These factors are 74.2%, ground level; 8.6%, zero to 500 m; and 18.67%, 500 m to 3000 m. These percentages are standardized from the original 735 five-pound charges set off at Fort Leonard Wood. Now a simple ratio can be determined by using the temperature inversion factors listed in Appendix C and the following derivation. This ratio is then multiplied to give a closer estimate to the actual SPL. The following terms are used in the calculations:

- IF1: Inversion Factor at ground level
- IF2: Inversion Factor at zero to 500 m
- IF3: Inversion Factor at 500 m to 3000 m
- d: distance in miles

• R: Ratio

STEP 1: Determine R

(1) If Day,

$$R = \frac{IF1 + IF2}{82.8}. \tag{16}$$

(2) If night and distance between source and receiver ≤ two miles,

$$R1 = \frac{IF1}{74.5}. \tag{17}$$

(3) If night and distance between source and receiver ≥ 10 miles,

$$R2 = \frac{IF3}{2(18.67)} + \frac{1}{2}. \tag{18}$$

(4) If night and distance between the source and receiver ≥ two miles but ≤ 10 miles,

$$R3 = \frac{R2 - R1}{.7} LOG_{10}\frac{d}{2} + R1. \tag{19}$$

STEP 2: Multiply R, R1, R2, or R3 by SPL to get corrected SPL. [Ref. 23:p. 122]

This is basically the general concept of how TABGEN takes into account the meteorological effect of temperature inversion. The current algorithm can now be modified to take into account temperature inversion.

2. UCCATS

UCCATS determines the sound level of opposing forces vehicles solely upon the distance between the source and receiver. Also, UCCATS sound system can be turned on and off. The assumptions that UCCATS make are the same as those listed in Chapter V, Section B-3 to include the following [Ref. 4:p. 3-28]:

(1) Every receiver is surrounded by its own sound. The sound level of each platform takes on either of two values depending upon whether or not the receiver is moving.

(2) The only sound that can conceal the sound of an enemy vehicle is the receivers intrinsic sound.

(3) Once a receiver detects an enemy vehicle his symbol will flash.

(4) Once an enemy target is detected it is always detected.

(5) UCCATS does not compare frequencies or dB level between various vehicles.

(6) Each increase of 10 dB in intensity of sound stimulus corresponds to doubling the sound level.

(7) The propagation of sound is modeled omnidirectional as a wave front expanding spherically from the source with pressure varying inversely proportional to the volume of the sphere with the given radius.

Due to the sixth assumption the following proportionality exists:

$$\frac{u}{x} \propto \frac{y^3}{v^3}, \tag{20}$$

where u dB occurs when measured at a distance of v from the source and x dB occurs when measured at a distance of y from

the source assuming a particular platform produces a source of sound. Due to the fifth assumption, that each increase of 10 dB in the intensity of sound stimulus causes a doubling in the sound level, (x + 10 dB) at y distance equals x dB at (y × ($2^{(1/3)}$)) distance. Since the sound waves propagating outwardly form a sphere the volume of a sphere (4/3)πr, where r is the radius of the sphere, will be utilized in deriving the relationships between the distances and sound level. It follows that

$$\frac{u}{x} = \frac{\frac{4}{3}\pi y^3}{\frac{4}{3}\pi v^3}. \tag{21}$$

Now let n = 1,2,3,... ;α = v/y; and u = x + (10 × n), since each doubling of sound level increase the sound stimulus by 10 dB then,

$$\frac{x + (10 \times n)}{x} = 2^n = \frac{y^3}{(y \times \alpha)^3}. \tag{22}$$

$$\Rightarrow \alpha^3 = (2^n)^{-1}$$

$$\Rightarrow \alpha = 2^{-n/3}$$

By substitution of -n = (x - (x + 10 × n))/10), α now equals

$$\alpha = ((2)^{\frac{1}{3}})^{(\frac{x - (x + (10 \times n))}{10}}. \tag{23}$$

Now place α in equation number 20 and get

$$\frac{u}{x} = \frac{y^3}{y(((2)^{\frac{1}{3}})^{(\frac{x-u}{10})})^3}. \qquad (24)$$

Let u = x - (x - u) and

$$\beta = ((2)^{\frac{1}{3}})^{(\frac{x-u}{10})} = \frac{v}{y} \qquad (25)$$

take natural logs of both sides and get

$$\ln\beta = (\frac{x-u}{10})(\frac{1}{3})\ln 2. \qquad (26)$$

Solving for u and get

$$u = x - (\frac{(3)(10)}{\ln 2})\ln\beta = x - (\frac{(3)(10)}{\ln 2})\ln\frac{v}{y}. \qquad (27)$$

Therefore, x dB at y distance equals u dB equation number 25 at v distance. Also, x dB at y distance equals u dB at v distance or by similar method as above

$$v = y(2^{((\frac{1}{3})*(\frac{(x-u)}{10})}) \qquad (28)$$

This concludes the derivation of u and v and shows and shows how UCCATS uses only distances to calculate the sound level of a platform. [Ref. 9]

E. ADVANTAGES/LIMITATIONS

This section will consolidate the advantages and limitations of the three existing acoustic algorithms discussed in Sections C and D. Then the section will conclude with a brief discussion of what algorithm should be utilized

on Janus(A) and what should be adapted from the other ones to improve the recommended algorithm.

1. ACOUSDET2

Advantages

(1) Currently available and can function on any Janus(A) system.

(2) Takes wind speed and some directions (upwind, downwind, and neutral) into account.

(3) The theoretical analysis took ground impedance and Ambient Noise Level into account.

(4) Acoustic data screens can be added to Janus(A) so that the user can modify some of the existing constants in the algorithm such as the degradation for terrain\vegetation and the degree of separation at which one target must be from another to be distinguished as a separate target.

(5) Displays different colored lines for wheeled vehicles, tracked vehicles, and helicopters detected and displays an "A" at the intersection of two lines to represent an approximate location of an enemy target.

Limitations

(1) No theoretical data supports detection distances for wheeled vehicles.

(2) Takes a standard 30% reduction for terrain and vegetation.

(3) The algorithm uses 15° as the limiting degree at which one target must be from another to be recognized as a separate target.

(4) Only takes the meteorological effect of wind into account.

2. BNOISE

Advantages:

(1) Takes temperature inversion into account.

(2) Written in FORTRAN 77 which is the same as Janus(A).

(3) Available through a U.S. Army agency, USA-CERL.

Limitations:

(1) Not written for a combat simulation model, therefore it may need considerable modifications.

(2) Only takes temperature inversion into account for meteorological effects affecting sound propagation.

3. UCCATS

Advantages:

(1) Currently being used in a combat simulation model.

(2) Symbols flash to indicate detection of enemy targets.

(3) Can only detect enemy targets.

(4) Intrinsic sound of receivers vehicle can conceal the sound of an enemy vehicle.

Limitations:

(1) Once an enemy target is detected it is always detected.

(2) Does not take into account any meteorological effects.

(3) Assumes that sound travels omnidirectionally expanding spherically from the source with pressure varying inversely proportional to the volume of the sphere with the given radius which is an over simplified assumption.

(4) Not written in FORTRAN 77.

After listing the advantages and limitations of the three algorithms available it is obvious that ACOUSDET2 should be adopted Army wide with some modifications. Further research could prove beneficial in this same area. The ACOUSDET2 subroutine should be modified to account for temperature inversion in the same manner as BNOISE accounts for it. As UCCATS does, ACOUSDET2 could be revised to consider the intrinsic sound of the receivers vehicle. Also, as discussed earlier an acoustic data screen should be added to Janus(A) so that the constants for vegetation/terrain degradation and the degree of separation at which one vehicle must be from another to be distinguished as a separate vehicle in ACOUSDET2 could be changed by the user. Finally, further research can be done to consider how to incorporate other meteorological effects into ACOUSDET2.

VI. ANALYSIS OF THE TUGV MODEL

A. GENERAL

This chapter examines the Janus(A) TUGV model in a tactical scenario. The Test and Evaluation Command (TEC) together with the U.S. Army Infantry School (USAIS) developed the scenarios which will be used to evaluate the TUGV. While this chapter is not meant to be an all inclusive test, it is designed to address the first Measures of Effectiveness (MOEs), previously listed in Chapter I of this thesis. The USAIS provided the authors the first three MOEs for the TUGV [Ref. 7:p. 6]. Thus this chapter will:

(1) determine whether a unit having a TUGV significantly increases its detection capabilities,

(2) determine how much varying the weather conditions affect the acoustic detection capabilities of the TUGV, and

(3) determine whether or not the proposed scenarios are feasible and assist in examining the difference between a unit with or without a TUGV.

Discussion of the final MOE, listed in Chapter I, identification of the cost effectiveness of adding a sound algorithm to the existing Janus(A) model, will occur in the concluding chapter. This chapter will first describe the

scenarios and test procedures of the test then present a statistical analysis of the resulting data.

B. DESCRIPTION OF SCENARIOS USED IN THE TEST

The design of the test of the Janus(A) model TUGV incorporated two different scenarios, an offensive mission and a defensive mission. Both offensive and defensive scenarios were examined with and without the TUGV. The defensive scenario consisted of a U.S. Army Infantry platoon in prepared defensive positions. This Infantry platoon included four M2 Bradley Fighting Vehicles (BFVs), 32 dismounted riflemen, and one battery of artillery. When the TUGV was included in the scenario, the TUGV was positioned four to five kilometers in front of the defensive positions. In order to test the scenario without the TUGV, two soldiers in an observation post equipped only with optical sensors, were positioned in the exact position as that of the TUGV's. Figure 8 on the following page is the initial set up of the defensive scenario including the TUGV and is included in order to graphically show the scenario to the reader.

Additionally, a scenario was used to test the TUGV model in the offense. This offensive scenario consisted of four M2 BFVs and was tested with and without the TUGV. When the TUGV was included in the scenario, it moved approximately two kilometers ahead and at approximately the same rate as the BFVs. However, when the TUGV was not included, two HMMWVs

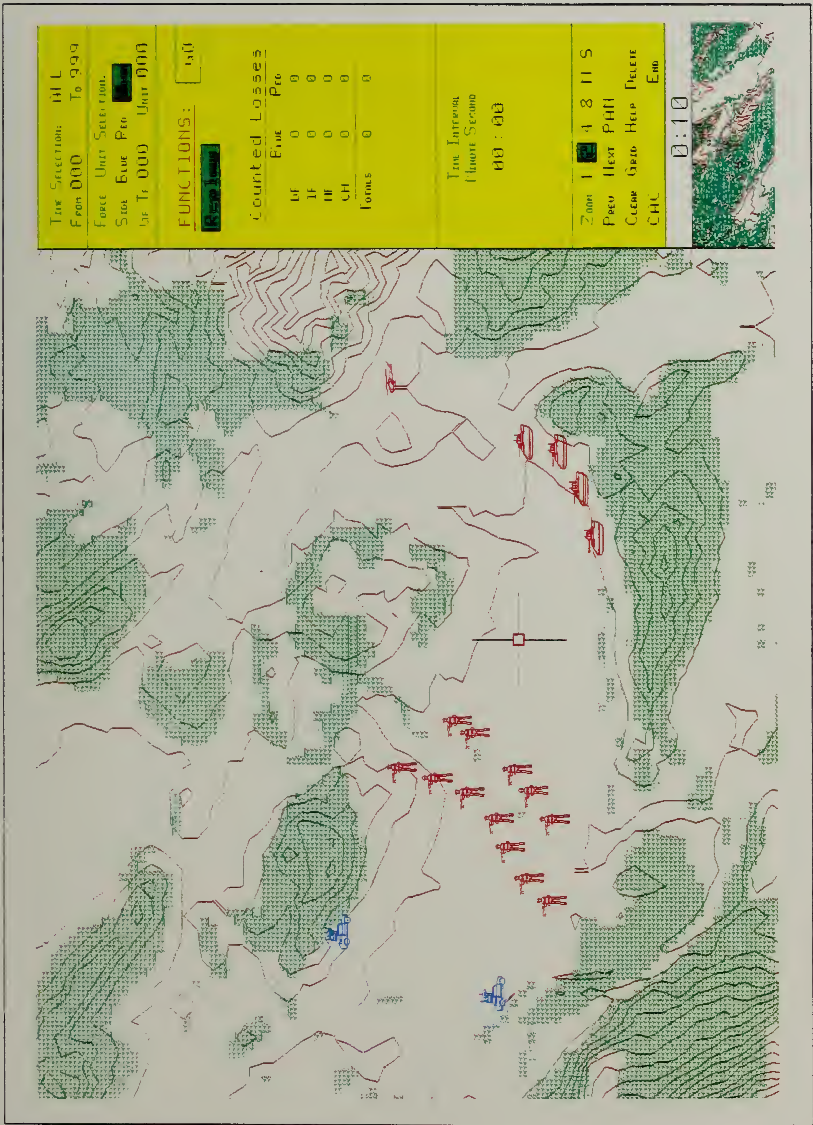

Figure 8 Defensive Scenario

moved along the identical routes of the TUGV's. The HMMWVs, for detection capabilities, were equipped with optical and thermal sights. Figure 9 on the following page is the initial set up of the offensive scenario including the TUGV and is included to amplify or help explain the scenario.

Additionally, in order to examine the effect of changing the weather conditions on the number of detections, the defensive and offensive scenarios were rerun both with and without the TUGV with a variation of the weather conditions. Initially, the defensive scenario was run with the weather conditions of a "clear" day in order to establish a baseline. Table 18 on page 72 lists the weather parameters first used. The weather was then changed to reflect decreased conditions at night. Therefore, a night scenario would forced the alternate sensor, thermal sensor, to be used. Table 19 on page 72 reflects the changed weather conditions.

Finally, the enemy, or red, forces used in both scenarios were also developed by the TEC and USAIS. The enemy force was primarily an infantry force consisting of four Soviet-styled Armored Personnel Carriers, BMPs, 12 dismounted automatic riflemen, and a battery of artillery. The red forces conducted an offensive mission when the blue force was in a defensive posture. Alternately, the red forces were in prepared defensive positions when the blue force was attacking or conducting an offensive mission.

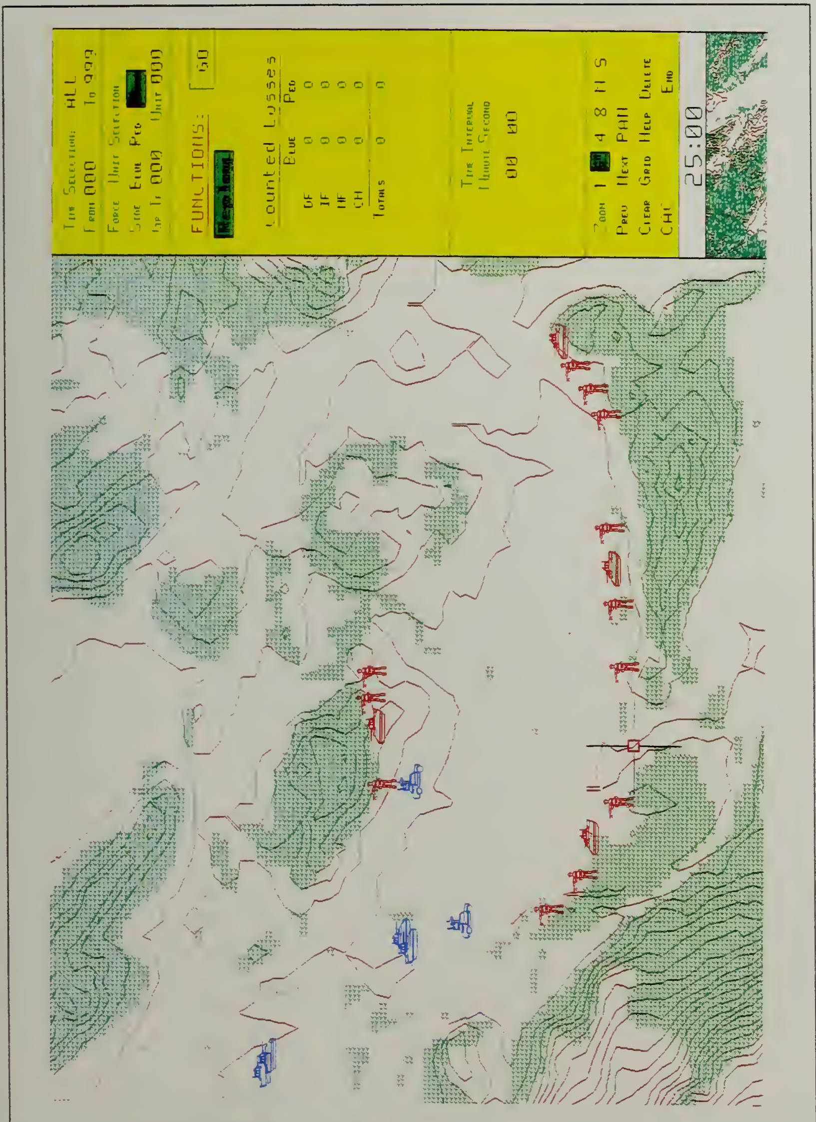

Figure 9 Offensive Scenario

TABLE 18 BASELINE WEATHER

BASELINE WEATHER CONDITIONS (CLEAR WEATHER CONDITIONS)	
Amount of Light	Daytime
Visibility	8000 m
Wind Direction	200 degrees from positive X-Axis Counter Clockwise
Wind Velocity	5.6 kph
Ceiling	1500 m above ground level
Relative Humidity	.95 or 95%
Temperature	75° Fahrenheit

TABLE 19 CHANGED WEATHER

CHANGED WEATHER CONDITIONS (OBSCURED WEATHER CONDITIONS)	
Amount of Light	Night
Visibility	3000 m
Wind Direction	270 degrees from positive X-Axis Counter Clockwise
Wind Velocity	3.6 kph
Ceiling	3500 m above ground level
Relative Humidity	.70 or 70%
Temperature	53.2° Fahrenheit

C. STATISTICAL ANALYSIS

The above test data is best explained by a collection of Latin Square designs [Ref. 24:p. 245]. When this type of design is applied to this experiment, the TUGV is considered as the treatment while at the same time this design has two blocks: mission, offense or defense, and weather, day/clear or night/obscured. Table 20 shows the Latin Square design for this experiment and is included in order to graphically depict the experiment methodology.

TABLE 20 LATIN SQUARE DESIGN

LATIN SQUARE DESIGN						
MISSION **WEATHER**	DEFENSE	DEFENSE		**MISSION** **WEATHER**	OFFENSE	DEFENSE
DAY/ CLEAR	TUGV	NO TUGV		DAY/ CLEAR	NO TUGV	TUGV
NIGHT/ OBSCURE	NO TUGV	TUGV		NIGHT/ OBSCURE	TUGV	NO TUGV

The data collected for the experiment was obtained from five runs or trials of each scenario. Appendix D lists the raw data for each trial for all scenarios. This data is broken down by type of sensor used for the detection either optical, thermal, or acoustic. The Analysis of Variance (ANOVA) table for this experiment is listed as Table 21 on the next page. Note here that the mean number of detections, (μ), for all scenarios which include the TUGV is 43.9 with a standard deviation (σ) of 32.54 compared to the μ for all

scenarios without the TUGV which is 22.8 with a σ = 12.48. Thus, with the TUGV included in the blue force, the average number of detections is nearly doubled.

TABLE 21 ANOVA TABLE

ANALYSIS OF VARIANCE PROCEDURE					
Dependent Variable: DETECTS					
SOURCE	**DF**	**SUM OF SQUARES**	**MEAN SQUARE**	**F VALUE**	**P VALUE**
Model	3	21826.70	7275.57	46.21	.0001
Error	36	5668.40	157.46		
Total	39	27495.10			
R-SQUARE .79384		C.V. 37.6256	ROOT MSE 12.54813	TOTAL DETECTIONS MEAN: 33.350	
SOURCE	**DF**	**SUM OF SQUARES**	**MEAN SQUARE**	**F VALUE**	**p VALUE**
Mission	1	17222.50	17222.50	109.38	.0001
Weather	1	152.10	152.10	.97	.3322
TUGV	1	4452.10	4452.10	28.28	.0001

MEAN NUMBER OF DETECTIONS WITH AND WITHOUT TUGV			
LEVEL OF EQUIPMENT	N	MEAN	SD
NO TUGV	20	22.80	12.4798785
TUGV	20	43.90	32.5412184

DF: Degree of Freedom
C.V.: Covariance
MSE: Mean Square Error
SD: Standard Deviation

While the shear number of detections increased with the TUGV included in the blue forces, this was not the only factor considered. As mentioned earlier, the effect of the two blocking variables, that of mission and weather, must be considered. In order to get an overall view of the results of each scenario, Table 22 below lists the mean number of detections for each scenario type.

TABLE 22 MEAN DETECTIONS

MEAN NUMBER OF DETECTIONS (ALL SCENARIOS CONSIDERED)	
SCENARIO TYPE	MEAN NUMBER OF DETECTIONS
TUGV INCLUDED	43.900
TUGV NOT INCLUDED	22.800
OFFENSIVE MISSION	12.600
DEFENSIVE MISSION	54.145
DAY/CLEAR WEATHER	34.345
NIGHT/OBSCURED WEATHER	31.400

In examining the "mission" blocking variable, the null hypothesis (H_o) states that a mission change from offense to defense would have no effect on the number of detections. Note from the ANOVA table (Table 21) the p-value is .0001 for the mission variable. A rejection value (α) > .01 was used in this test. Thus the H_o is rejected and, in fact, the type of mission did significantly affect the number of detections. In the experiment, the defense mission produced the greatest

number of detections with a μ = 54.145 compared with the μ detections for the offense mission of 12.6. An explanation for this difference lies in the ability of the TUGV to detect on the move. When the TUGV is moving as in the offensive scenarios, the acoustic detector is incapable of detecting enemy forces. Therefore, the TUGV was stopped several times along its route of march to give the acoustic sensor the opportunity to detect. Thus, in the defensive scenarios, the TUGV is stationary and is capable of detecting enemy forces acoustically at all times. Therefore, this model shows that the TUGV is most effective in a defensive posture.

In examining the "weather" blocking variable, the H_o would read that the specified weather change would have no effect on the number of detections. Referring to the ANOVA table (Table 21), the p-value associated with the weather blocking variable is .3322. Again α > .01 was used in this test. Therefore, since the p-value of .3322 > .01 there exists significant evidence to indicate a failure to reject H_o. The mean number of detection for clear, day weather was μ = 35.345, while for the obscured, night weather μ = 31.40. Thus the weather changes, as specified, did not significantly affect the number of detections.

By examining all acoustic detections of all scenarios and comparing this number to the total number of detections (for all sensors), one can get an understanding of the contribution of adding the acoustic sensor to the model. In all scenarios

involving the TUGV, the model provided 174 total acoustic detections and 1554 total detections for all sensors. This equates to a contribution of 11.197% by adding the acoustic sensor. While the model is stochastic in nature and the outcome depends on a random number seed, one can assume that the overall contribution of adding the acoustic sensor to the TUGV model is slightly greater than 10%.

In examining the MOEs, the above results indicate that a unit having a TUGV will, in fact, significantly increase its detection capabilities provided the unit employed the TUGV in a defensive mission. Additionally, the second MOE, that of varying weather conditions, did not significantly affect the number of detections. Finally, the last Measure of Effectiveness, determining the feasibility of the proposed scenarios, is answered by the above analysis. The differences measured in changing mission and the use of the TUGV produces a statistical significance in mean number of detections. Also, the fact that changing the weather did not significantly affect the number of detections is important for the future testing and employment of the TUGV.

VII. CONCLUSION

A. CONCLUSION

The model of the Tactical Unmanned Ground Vehicle is a relatively good model in terms of fidelity, flexibility, and cost. Fidelity refers to how the model actually represents reality and, aside from minor shortcomings, represents the TUGV prototype well. Additionally, the model is extremely flexible since changes in the model can be made rapidly. Finally, since the TUGV was modeled in an existing computer assisted environment, the model is extremely low in cost. [Ref. 25]

Based on the results of the research, a unit equipped with the TUGV will significantly increase its ability to perform a detection mission. Further, a unit in a stationary defensive posture is best able to perform this detection mission since the TUGV model can only acoustically detect while not moving. Finally, adding an acoustic sensor to the TUGV increases its total detections by approximately 11%. Therefore, the addition of an acoustic sensor to the TUGV model significantly increases its detection capabilities.

B. RECOMMENDATIONS

In order to improve and further this research effort the authors recommend the following:

(1) Improve the model

a. Establish a link in the model between the TUGV and a direct or indirect fire asset to examine survivability.

b. Add/improve capabilities to the TUGV model as the capabilities become part of the TUGV prototype.

(2) Incorporate the existing acoustic detection subroutine to Janus(A) users system wide.

(3) Improve the existing acoustic detection subroutine, ACOUSDET2, by creating an acoustic data screen in which the user could manually alter the vegetation/terrain degradation and the degree at which one target must be from another to be distinguished as a separate target.

(4) Improve ACOUSDET2 by incorporating temperature inversion and the intrinsic sound of the receivers vehicle into the algorithm.

(5) Consider how other meteorological effects such as humidity affect the propagation of sound and incorporate it into ACOUSDET2.

APPENDIX A

This appendix includes the necessary graphs for calculating the probability of detection (P_d) and probability of identification (P_{id}) at 90%, 50%, and 10% for M60 at 20 mph, M1 Abrams at idle, M1 Abrams at 20 mph, and UH1 helicopter. The tables following each graph on the subsequent pages refer to that particular graph. The calculations for all tables in this appendix are based upon a f = 100 Hz. The procedure used for all calculations follows the steps derived in Chapter V, Section C, Subsection 1. At the end of this appendix are two graphs, Figures 14 and 15 which can be used to calculate P_d's and P_{id}'s at frequencies of 50 Hz and 10 Hz. TRAC WSMR did not utilize the frequencies of 50 Hz and 10 Hz. Therefore, the calculations for 50 Hz and 10 Hz are not provided in this thesis; however, the procedure for calculating the P_d's and P_{id}'s for 50 Hz and 10 Hz is identical to that presented in Chapter V of this thesis.

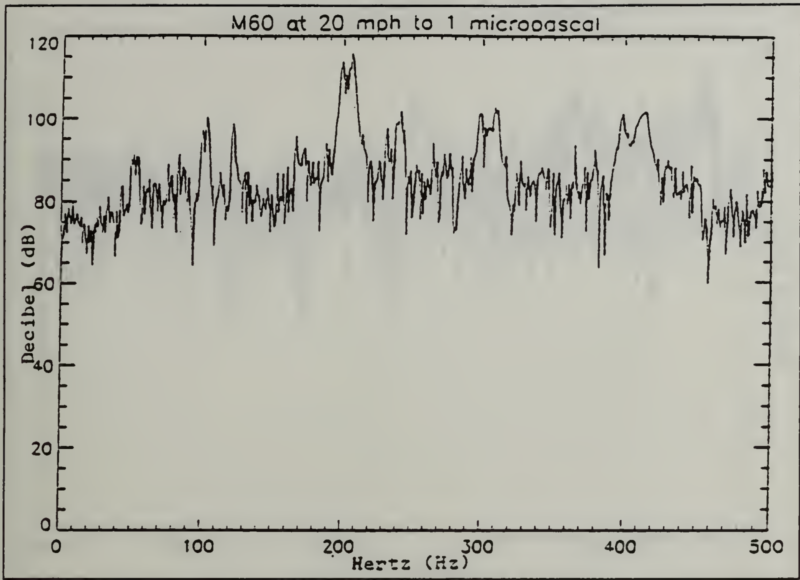

Figure 10 Spectral Analysis M60 at 20 mph

TABLE 23 P_d's M60 AT 20 MPH

P_d	TL	NEUTRAL	DOWNWIND	UPWIND
90%	90.2	5.9 Km	8.0 Km	1.6 Km
50%	91.6	7.0 Km	10.0 Km	1.8 Km
10%	93.1	8.5 Km	12.0 Km	1.9 Km

TABLE 24 P_{id}'s M60 AT 20 MPH

P_{id}	TL	NEUTRAL	DOWNWIND	UPWIND
90%	90.2	4.7 Km	6.4 Km	1.3 Km
50%	91.6	5.6 Km	8.0 Km	1.4 Km
10%	93.1	6.8 Km	9.6 Km	1.5 Km

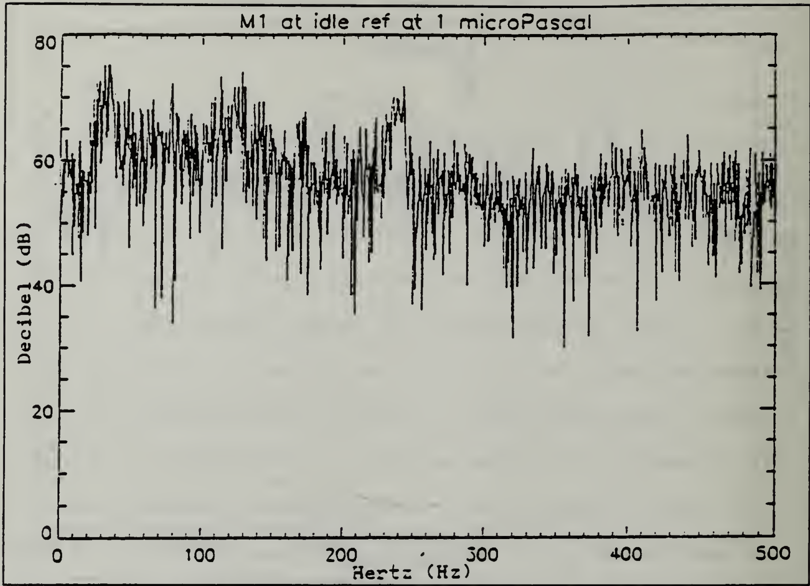

Figure 11 Spectral Analysis M1 at Idle

TABLE 25 P_d's M1 AT IDLE

P_d	TL	NEUTRAL	DOWNWIND	UPWIND
90%	53.2	.5 Km	.7 Km	.5 Km
50%	54.6	.6 Km	1.0 Km	.6 Km
10%	56.1	.7 Km	1.5 Km	.7 Km

TABLE 26 P_{id}'s M1 AT IDLE

P_{id}	TL	NEUTRAL	DOWNWIND	UPWIND
90%	53.2	.40 Km	.56 Km	.40 Km
50%	54.6	.48 Km	.80 Km	.48 Km
10%	56.1	.56 Km	1.20 Km	.56 Km

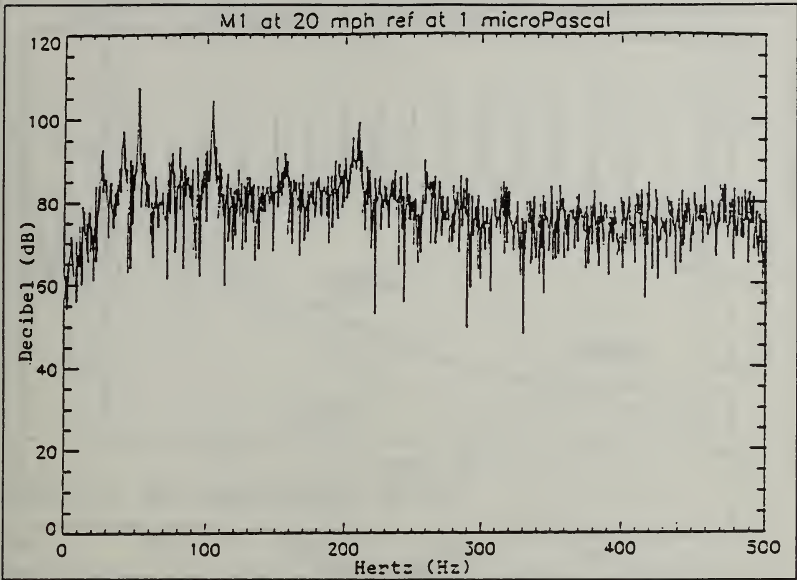

Figure 12 Spectral Analysis M1 at 20 mph

TABLE 27 P_d's M1 AT 20 MPH

P_d	TL	NEUTRAL	DOWNWIND	UPWIND
90%	85.2	4.5 Km	6.0 Km	1.3 Km
50%	86.6	5.4 Km	7.5 Km	1.5 Km
10%	88.1	6.2 Km	9.0 Km	1.8 Km

TABLE 28 P_{id}'s M1 AT 20 MPH

P_{id}	TL	NEUTRAL	DOWNWIND	UPWIND
90%	85.2	3.6 Km	4.8 Km	1.0 Km
50%	86.6	4.3 Km	6.0 Km	1.2 Km
10%	88.1	5.0 Km	7.2 Km	1.4 Km

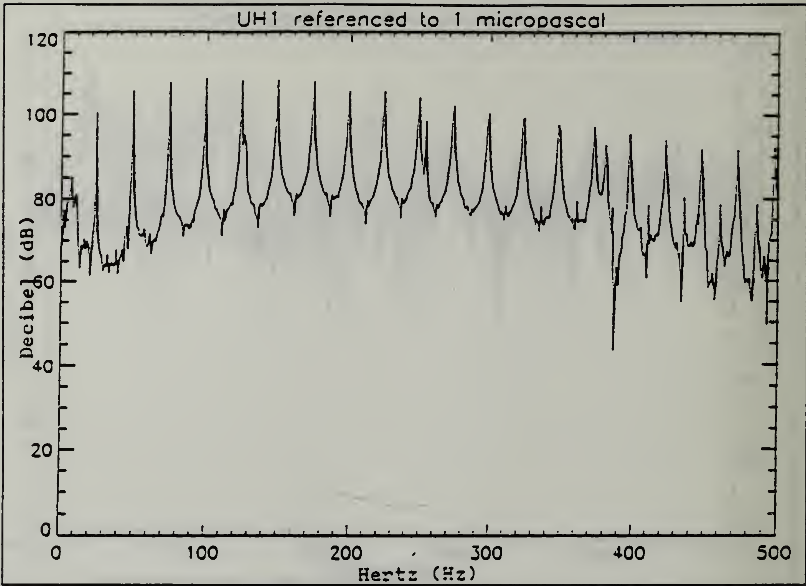

Figure 13 Spectral Analysis UH1

TABLE 29 P_d's UH1

P_d	TL	NEUTRAL	DOWNWIND	UPWIND
90%	93.199	10.0 Km	11.0 Km	2.25 Km
50%	94.604	11.0 Km	12.0 Km	2.30 Km
10%	96.101	12.0 Km	13.0 Km	2.50 Km

TABLE 30 P_{id}'s UH1

P_{id}	TL	NEUTRAL	DOWNWIND	UPWIND
90%	93.199	8.0 Km	8.8 Km	1.80 Km
50%	94.604	8.8 Km	9.6 Km	1.84 Km
10%	96.101	9.6 Km	10.4 Km	2.00 Km

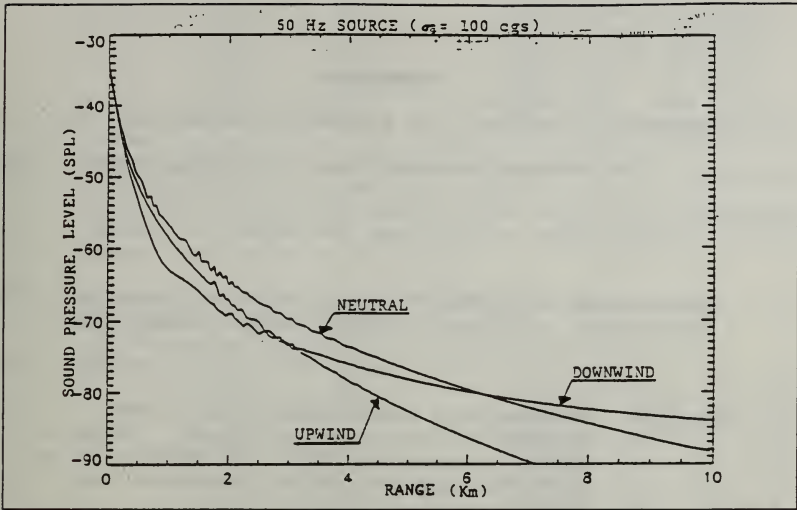

Figure 14 SPL Versus Range (50 Hz)

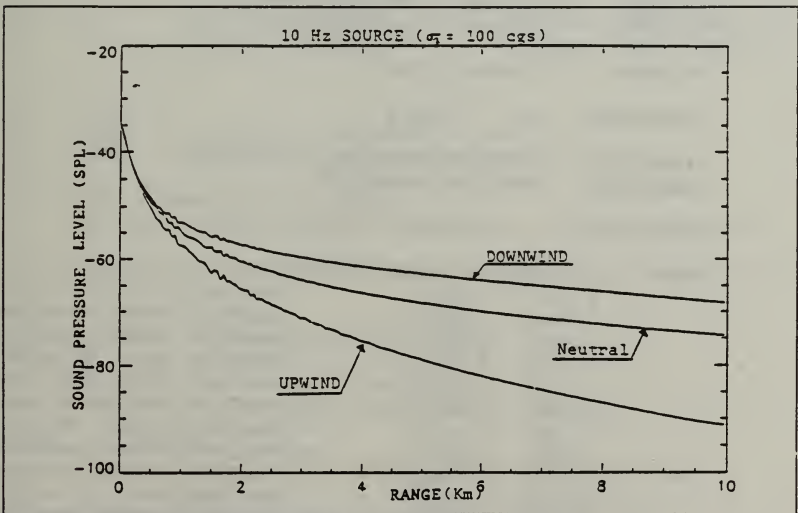

Figure 15 SPL Versus Range (10 Hz)

APPENDIX B

This appendix includes the subroutine ACOUSDET2 which the authors of this thesis acquired from Mr. Barney Watson at TRAC WSMR.

```
C----SUBROUTINE--ACOUSDET2-----------------S E GALLOWAY, WSMR
     SUBROUTINE  ACOUSDET2 ( IUNIT,ISIDE, JUNIT,JSIDE )

C----------------------------------------------------------C
C                                                          C
C  FUNCTION:  To determine which targets have been         C
C             detected by the acoustic sensor.  Targets    C
C             within a specified area (15 degrees) of a    C
C             target already picked be considered the      C
C               same target.                               C
C---------------------------------------------------------C

     INCLUDE     'JGLOBE:GLOBAL.FOR'
     INCLUDE     'JGLOBE:GLOBUNITS.FOR'
     INCLUDE     'JGLOBE:GLBWETHR.FOR'

     INCLUDE     'GLOBBTS.FOR'

     PARAMETER   PI = 3.14159

     DIMENSION   ACRNGTGT(NUMBTSU,NUMTGTSEN)
     DIMENSION   INUMTGTS(NUMBTSU)

     DATA SAVCLK  / 9999.0 /

     DATA ((((BTSRNG(M,L,K,J),J=1,2),K=1,3),L=1,2),M=1,3)
  *       /  0.273,  0.390,        ! WHEELED, STAT, UP WIND
  *          1.344,  1.920,        ! WHEELED, STAT, DWN WIND
  *          0.987,  1.410,        ! WHEELED, STAT, NEUTRAL
  *          0.273,  0.390,        ! WHEELED, MOV, UP WIND
  *          1.344,  1.920,        ! WHEELED, MOV, DWN WIND
  *          0.987,  1.410,        ! WHEELED, MOV, NEUTRAL
  *          0.910,  1.300,        ! TRACKED, STAT, UP WIND
  *          4.480,  6.400,        ! TRACKED, STAT, DWN WIND
  *          3.290,  4.700,        ! TRACKED, STAT, NEUTRAL
  *          0.910,  1.300,        ! TRACKED, MOV, UP WIND
  *          4.480,  6.400,        ! TRACKED, MOV, DOWN WIND
  *          3.290,  4.700,        ! TRACKED, MOV, NEUTRAL
```

```
  *           1.800,  1.800,         ! HELO, STAT, UP WIND
  *           8.800,  8.800,         ! HELO, STAT, DWN WIND
  *           8.000,  8.000,         ! HELO, STAT, NEUTRAL
  *           1.800,  1.800,         ! HELO, MOV, UP WIND
  *           8.800,  8.800,         ! HELO, MOV, DWN WIND
  *           8.000,  8.000 /        ! HELO, MOV, NEUTRAL
C-----------------------------------------------------------------
C    N = Visibility  - LOS Obscured by Terrain
C    Y = Visibility - Clear LOS, PLOS = 1.0
C    Upwind, Downwind, & Neutral Wind directions data for
C    sensor to target Ref Memorandum: LABCOM/S3TO - Acoustic
C    Sensor Performance (30 Jun 92)
C
C    Changed: 24 July 92 by CW4 per Barney W.
C    Wheeled 30% of original data
C    LOS obscured by Terrain 70% of Non-Obscured
C    Below is original data:
C    *    / 1.300,  1.300,         ! WHEELED, STAT, UP WIND
C    *      6.400,  6.400,         ! WHEELED, STAT, DWN WIND
C    *      4.700,  4.700,         ! WHEELED, STAT, NEUTRAL
C    *      1.300,  1.300,         ! WHEELED, MOV, UP WIND
C    *      6.400,  6.400,         ! WHEELED, MOV, DWN WIND
C    *      4.700,  4.700,         ! WHEELED, MOV, NEUTRAL
C    *      1.300,  1.300,         ! TRACKED, STAT UP WIND
C    *      6.400,  6.400,         ! TRACKED, STAT, DWN WIND
C    *      4.700,  4.700,         ! TRACKED, STAT, NEUTRAL
C    *      1.300,  1.300,         ! TRACKED, MOV, UP WIND
C    *      6.400,  6.400,         ! TRACKED, MOV, DWN WIND
C    *      4.700,  4.700,         ! TRACKED, MOV, NEUTRAL
C----------------------------------------------------------------

D    TYPE *
D    TYPE *,' ******** ACOUSDET ********* '
D    TYPE *

C----Get sensor and tgt types
     ITYPE = KSYSTYP(IUNIT,ISIDE)              ! UNIT TYPE

     JTYPE = KSYSTYP(JUNIT,JSIDE)              ! TARGET TYPE

C----Pull BTS slot
     IBTSLOT = KBTSSLOT(IUNIT,ISIDE)

C----Location of acoustic sensor
     CALL UNITXYZ( IUNIT,ISIDE,ITYPE,X0,Y0,Z0 )

C----Location of target
     CALL UNITXYZ( JUNIT,JSIDE,JTYPE,XTGT,YTGT,ZTGT )

C----Determine angle and limits for display fan
     DELTAX = XTGT - X0
```

```
      DELTAY = YTGT - Y0

      DISTSQ = DELTAX**2 + DELTAY**2
      DIST   = SQRT(DISTSQ)

C----Orientation angle (-179 - +180 degrees)
      ANG = ATAN2(DELTAY,DELTAX)

C----Convert orientation angle from (-179 to 180) -> (0 -
C----360) degrees
      ANGL = ANG
      IF (ANG .LT. 0.0 ) ANGL = 2*PI + ANGL

C----Windir is in degrees, convert orientation angle to
C----degrees
      ANGD = ANGL*180.0/PI

C----Determine angle between tgt/sensor and windir
      ANGDIF = ABS(WINDIR - ANGD)

C----Determine Up Wind, Down Wind or Neutral
      IF (ANGDIF .GE. 0.0 .AND. ANGDIF .LT. 60.0) THEN

C-------Sensor upwind data (target downwind)
         IWIND = 1

      ELSEIF (ANGDIF .GE. 60.0 .AND. ANGDIR .LT. 120.0) THEN

C-------Sensor neutral data (target neutral)
         IWIND = 3

      ELSE

C-------Sensor downwind data (target upwind)
         IWIND = 2
      ENDIF

C----Determine the status, 0 - not detect, 1 - approx lob,
C----2 - accurate lob
      MTYPE = 0
      IF (FLYERS(JTYPE,JSIDE) .GT. 0) MTYPE = 3     ! HELO
      IF (MOVERS(JTYPE,JSIDE) .EQ. 2) MTYPE = 2     ! TRACKED
      IF (MOVERS(JTYPE,JSIDE) .EQ. 1) MTYPE = 1     ! WHEELED
      IF (MTYPE .LE. 0) GOTO 900

      ISPDU = 1                               ! STATIONARY, HOVERING
      IF (SPDU(JUNIT,JSIDE) .GT. 0.0) ISPDU = 2      ! MOVING

C----Determine Visibility

      CALL DOLOS ( X0,Y0,Z0,XTGT,YTGT,ZTGT,PLOS )
```

```
      IVISB = 2                                            ! CLEAR LOS
      IF (PLOS .LT. 1.0) IVISB = 1                         ! OBSCURED LOS

C----Effective range for BTS
      EFFRNG = BTSRNG(MTYPE,ISPDU,IWND,IVISB)

C----Detection status
      ISTAT = 0
      IF (DIST .LE. EFFRNG) ISTAT = 5     ! ACOUSTIC DETECTION

C----If not detected exit
      IF ( ISTAT .LE. 0 ) GOTO 900

C----If new pass, zero arrays
      IF( CLOCK .NE. SAVCLK ) THEN

          DO IS = 1,KBTSCNT
             DO IT = 1 ,NUMTGTSEN
                ACRNGTGT(IS,IT)     = 0.0
                KACTGTLST(IS,IT)    = 0
                KACTGTSID(IS,IT)    = 0
                INUMTGTS(IS)        = 0
                ACOUCEPX(IS,IT)     = 0.0
                ACOUCEPY(IS,IT)     = 0.0
                ACANGLOB(IS,IT)     = 0.0
                ACEFFRNG(IS,IT)     = 0.0
                KACHEAR(IS,IT)      = 0
             ENDO
          ENDO

          SAVCLK = CLOCK

      ENDIF

C----Calculate CEP (circular error probability) in meters
      DISMTR = DIST * 1000.00
      ACOUSCEP = DISMTR*10**(-1.514+(DISMTR*(8.72*0.00001)))

      IF(ACOUSCEP .GT. 2000.0) ACOUSCEP = 2000.0

C----Set min for x,y
      XMIN = XTGT - ACOUSCEP*0.0001
      YMIN = YTGT - ACOUSCEP*0.0001

C----(XTGT-CEP,YTGT-CEP)|__(XTGT,YTGT)__|(XTGT+CEP,YTGT+CEP)
C----                   |____2 * CEP____|
C----              |Want new pt to fall in here|
C----Remember CEP is in meters, must convert to KM to
C----determine new x,y

C----Draw to determine x location
```

```
      CALL UNIRAN(DRWX)
      CEPX = XMIN + 2*ACOUSCEP*0.0001*DRWX

C----Draw to determine y location
      CALL UNIRAN(DRWY)
      CEPY = YMIN + 2*ACOUSCEP*0.0001*DRWY

C----Determine if it is within the LOB ANGLE to already
C----picked tgts
      DO 125 ITGT = 1,INUMTGTS(IBTSLOT)

         DELANG = ABS(ACANGLOB(IBTSLOT,ITGT) - ANGD)

C------If within Acoustic area of interest, same tgt
        IF(DELANG .LT. (ACAOI(IBTSLOT)/2.0)) THEN

C---------Save highest priority heard within cluster
          IF(MTYPE .GT. KACHEAR(IBTSLOT,ITGT))
     *       KACHEAR(IBTSLOT,ITGT) = MTYPE

C---------Save closes dist within this cluster
          IF(DIST .LT. ACRNGTGT(IBTSLOT,ITGT))
     *       ACRNGTGT(IBTSLOT,ITGT) = DIST

C---------Save max effective range within this cluster
          IF(EFFRNG .LT. ACEFFRNG(IBTSLOT,ITGT))
     *       ACEFFRNG(IBTSLOT,ITGT) = EFFRNG

          GOTO 900
        ENDIF
 125  CONTINUE

C----Valid target, determine if room in array
      IF(INUMTGTS(IBTSLOT) .LT. NUMTGTSEN) THEN

C------Empty slot, save target and exit
        INUMTGTS(IBTSLOT) = INUMTGTS(IBTSLOT) + 1
        I = INUMTGTS(IBTSLOT)
        ACRNGTGT(IBTSLOT,I)    = DIST
        KACTGTLST(IBTSLOT,I)   = JUNIT
        KACTGTSID(IBTSLOT,I)   = JSIDE
        ACOUCEPX(IBTSLOT,I)    = CEPX
        ACOUCEPY(IBTSLOT,I)    = CEPY
        ACANGLOB(IBTSLOT,I)    = ANGD
        ACEFFRNG(IBTSLOT,I)    = EFFRNG
        KACHEAR(IBTSLOT,I)     = MTYPE

        KBTSADET = KBTSADET + 1
          GOTO 900
      ENDIF
```

```
C----No empty Slot, bump largest range if this distance
C----shorter.  Don't want to change JUNIT the argument,
C----store in local variable
      JTGT = JUNIT
      JSID = JSIDE

 150 CONTINUE

      DO 200 I = 1,NUMTGTSEN

          ADIST = ACRNGTGT(IBTSLOT,I)

          IF(DIST .LT. ADIST) THEN
C-----------Save current stored value
             SAVRNG  = ACRNGTGT(IBTSLOT,I)
             ISAVTGT = KACTGTLST(IBTSLOT,I)
             ISAVSID = KACTGTSID(IBTSLOT,I)
             SAVX    = ACOUCEPX(IBTSLOT,I)
             SAVY    = ACOUCEPY(IBTSLOT,I)
             SAVLOB  = ACANGLOB(IBTSLOT,I)
             SAVEFF  = ACEFFRNG(IBTSLOT,I)
             ISHEAR  = KACHEAR(IBTSLOT,I)

C-----------Store smaller value
             ACRNGTGT(IBTSLOT,I)     = DIST
             KACTGTLST(IBTSLOT,I)    = JTGT
             KACTGTSID(IBTSLOT,I)    = JSID
             ACOUCEPX(IBTSLOT,I)     = CEPX
             ACOUCEPY(IBTSLOT,I)     = CEPY
             ACANGLOB(IBTSLOT,I)     = ANGD
             ACEFFRNG(IBTSLOT,I)     = EFFRNG
             KACHEAR(IBTSLOT,I)      = MTYPE

C-----------Check displaced JTGT against others saved
             DIST    = SAVRNG
             JTGT    = ISAVTGT
             JSID    = ISAVSID
             CEPX    = SAVX
             CEPY    = SAVY
             ANGD    = SAVLOB
             EFFRNG  = SAVEFF
             MTYPE   = ISHEAR
             GOTO 150
          ENDIF

 200 CONTINUE
 900 CONTINUE
C----RETURN to calling routine

      RETURN
      END
```

The following is a list of files used by the authors of this thesis to enable the acoustic algorithm to function on the TUGV.

```
Save set:              JANUS.BAK
Written by:            SCRATCH
UIC:                   [000277,000277]
Date:                  1 Mar 1993
Command:               BACKUP/LOG/LAB=TAPE/VER *.* MUAO:JANUS.BAK
Operating system       VAX/VMS version V5.4
BACKUP version:        V5.4
CPU ID register:       08000000
Node name:             _SEND::
Written on:            _MUA0:
Block size:            8192
Group size:            10
Buffer count:          67

[SCRATCH.MTRY_ACOU]ACOUSDET2.OBJ;1        6      1 MAR 93
[SCRATCH.MTRY_ACOU]BACKUP.COM;2           1      1 MAR 93
[SCRATCH.MTRY_ACOU]BTSDET.OBJ;1           5      1 MAR 93
[SCRATCH.MTRY_ACOU]CLRTGTS.OBJ;1          2      1 MAR 93
[SCRATCH.MTRY_ACOU]DETECT.OBJ;1          12      1 MAR 93
[SCRATCH.MTRY_ACOU]DRWBTS2.OBJ;1          6      1 MAR 93
[SCRATCH.MTRY_ACOU]DSTLOS.OBJ;1           6      1 MAR 93
[SCRATCH.MTRY_ACOU]FORMS.OLB;2          274     17 FEB 93
[SCRATCH.MTRY_ACOU]GRAFAK.OLB;2         206     17 FEB 93
[SCRATCH.MTRY_ACOU]HANDOFF.OBJ;1          5      1 MAR 93
[SCRATCH.MTRY_ACOU]HNRANGE.OBJ;1          6      1 MAR 93
[SCRATCH.MTRY_ACOU]INITMAIN.OBJ;1        11      1 MAR 93
[SCRATCH.MTRY_ACOU]JANUS.EXE;1         1140      1 MAR 93
[SCRATCH.MTRY_ACOU]JANUS.OBJ;2            2     16 FEB 93
[SCRATCH.MTRY_ACOU]JANUS.OLB;4         1719     17 FEB 93
[SCRATCH.MTRY_ACOU]KILL.OBJ;1             6      1 MAR 93
[SCRATCH.MTRY_ACOU]MAKEJAN.COM;3          2      1 MAR 93
[SCRATCH.MTRY_ACOU]README.DOC;1           1      1 MAR 93
[SCRATCH.MTRY_ACOU]RUNJAN.OBJ;1           5      1 MAR 93

Total of 19 files, 3415 blocks
End of save set
```

APPENDIX C

This appendix includes the subroutine READTB which calculates the temperature inversions for the BNOISE program discussed in Chapter V, Section D. In order to fully understand how BNOISE works one must look at the entire program which is available through USA-CERL. By calling 1-800-USA-CERL one can ask for and receive Technical Report N-86/12 dated June 1986 which is a User's Manual for BNOISE. Also, USA-CERL will provide upon request a disk copy of BNOISE which can be utilized on any IBM-PC compatible computer.

```
C*********SUBROUTINE TEADTB**********************************
C
C  READS INFORMATION FOR TABGEN (FOUND IN TAPE 20) AND
C  MODIFIES IT ACCORDING TO THE INVERSION FACTORS GIVEN IN
C  THE CALLING SUBROUTINE.  THE TABLES ARE UNDER THE
C  CONDITIONS OF STANDARD PERCENT TEMPERATURE INVERSION
C  FACTORS.
C
C***********************************************************
      COMMON/IO/KARD,KPRINT
      COMMON/FACTI/RINV1,RINV2,RINV3
      COMMON/DEBUG/CHECK,REED,TABRD
      COMMON/PARM/THRESH,PENITE
      LOGICAL CHECK,REED,TABRD

C     COMMON BLOCK TABL1 CONTAINS THE TABLES OF PROGRAM TABGEN
C     FOUND IN TAPE 20
C     DBV = TABLE OF DB VALUES
C     PERV = TABLE OF PERCENTAGES
C     ENV = TABLE OF ENERGY VALUES
C     CSCF = TABLE OF CHARGE SIZE CORRECTION FACTORS
C     FON1 AND FON2 ARE USED IN F1 COMPUTATION
C     FTWD IS USED IN F2 COMPUTATION

      COMMON/TABL1/ DBV(301,9,2), PERV(310,4,2), ENV(1501)
     1  CSCF(601), FON1(301,4,2),FON2(301,4,2),FTWO(151,2)
```

```
      DATA IN1/20/
      REWIND IN1

C     THIS READS THE STANDARD PERCENT TEMPERATURE INVERSION
C     FACTORS FROM TAPE20.

      READ (IN1) PC1,PC2,PC3

C     ERROR..DB,PERCENT CURVE TABLES MISSING--PROGRAM ABORTED*

      IF(EOF(IN1).GT.0.0) GOTO 999

C     L = 1 IS DAY
C     L = 2 IS NIGHT
C     J = 1 FOCUS MAX
C     J = 2 FOCUS MEAN
C     J = 3 BASE MAX
C     J = 4 BASE MEAN
C     J = 5 NEG MAX
C     J = 6 NEG MEAN
C     J = 7 EX NEG MAX
C     J = 8 EX NEG MEAN
C     J = 9 EX NEG MIN

      DO 20 L = 1,2
      DO 20 J = 1,9

C     READ DB VALUES FROM TAPE 20 INTO ARRAY DBV.

      READ (IN1) (DBV(I,J,L),I = 1,301)
20    CONTINUE

C     L = 1 IS DAY
C     L = 2 IS NIGHT
C     J = 1 FOCUS
C     J = 2 BASE
C     J = 3 NEG
C     J = 4 EX NEG

      DO 30 L = 1,2
      DO 30 J = 1.4

C     READ PERCENT VALUES FROM TAPE 20 INTO ARRAY PERV.

      READ (IN1) (PERV(I,J,L),I = 1,301)

30    CONTINUE

C     CSCF-CHARGE SIZE CORRECTION FACTOR

      READ (IN1) CSCF
```

```
C   COMPUTE CORRECTION FACTORS FOR THE INVERSION FACTORS.
C   DISTANCE BETWEEN SOURCE AND POINT < 2 MILES.  DISTANCE >
C   10 MILES      2<DISTANCE<10.

    RO = (RINV1 + RINV2)/(PC1 + PC2)
    R1 = RINV1/PC1
    R2 = ((RINV3 - PC3)/2.0 + PC3)/PC3

C   CORRECT THE PERCENTAGE

    DO 100 K = 1,2
    DO 100 J = 1,301
    BASE = PERV(J,2,K)
    FOCUS = PERV(J,1,K)
    GNEG = PERV(J,3,K)
    EXNEG = 100.0 - (BASE + FOCUS + GNEG)
    IF (K.EQ.1) RATIO = RO

C   2 MILES OR LESS  (152)
C   100*ALOG10((2 MILE)*(5280 FEET/MILE)*(.3048 METER/FEET))
C   - 199)

    IF (K.EQ.2.AND.J.LT.152) RATIO = R1

C   10 OR GREATER    (222)

    IF (K.EQ.2.AND.J.GT.222) RATIO = R2

C   BETWEEN 2 AND 10

    IF (K.EQ.2.AND. (J.LE.222.AND.J.GE.152))
   1 RATIO = (R2-R1) * (J-152)/70.0 + R1
    B1 = BASE * RATIO
    F1 = FOCUS * RATIO
    DELB = BASE - B1 + FOCUS - F1
    DELN = GNEG/(GNEG + EXNEG) * DELB
    GN1 = GNEG + DELN
    IF (F1.LT.0.) F1 = 0.
    IF (B1.LT.0.) B1 = 0.
    IF (GN1.LT.0.) GN1 = 0.
    PERV(J,1,K) = F1/100.
    PERV(J,2,K) = B1/100.
    PERV(J,3,K) = GN1/100.
    PERV(J,4,K) = (100.-F1-B1-GN1)/100.
100 CONTINUE

C   FONE
C   F1 COMPUTATION

    TLT = 10.0 / ALOG (10.0)
    THRSH = 10.0**(THRESH/10.0)
```

```
      DO 50 I = 1,301
      DO 50 J = 1,4
      DO 50 K = 1,2
      RMEAN = DBV(I,J*2,K)
      RMAX = DBV(I,J*2-1,K)
RMIN = DBV(I,J*2+1,K)

C     GET THE K FACTOR

      RK = (TLT*(10.**((RMAX-RMEAN)/10.)-1.0)-(RMAX-RMEAN)) /
     1   ((RMEAN-RMIN)-(TLT * (1.0-10.**((RMIN-RMEAN)/10.))))

C     CASE ONE

      FON1(I,J,K)= TLT*THRSH*RK/(RK*(RMEAN-RMIN)+(RMAX-RMEAN))

C     CASE TWO

      FON2(I,J,K) = TLT*THRSH/(RK*(RMEAN-RMIN(+(RMAX-RMEAN))
50    CONTINUE

C     FTWO

      DO 60 I = 1,151

C     CASE 1
C     F2 COPUTATION

      FTWO(I,1) = 1.0 - 10.0**((1 - I)/100.0)

C     CASE 2

      FTWO(I,2) = 10.0**((I - 1)/100.0) - 1.0
60    CONTINUE

C     DB TO ENERGY

      DO 70 I = 1,1501

C     CHANGE DB TO ENERGYA.  STORE IN ARRAY ENV.

      ENV(I) = 10.0**((I + 249)/100.0)
70    CONTIUNE

C     CORRECT FOR NIGHT TIME VALUES

      DO 80 I = 1,301
      DO 80 J = 1,9

C     NIGHTIME CORRECTION FACTOR.
```

```
      DBV(I,J,2) = DBV(I,J,2) + PENITE
 80   CONTIUNE

C     LOGICAL FLAG IS TRUE AFTER THE EXECUTION OF THE
C     SUBROUTINE

      TABRD = .TRUE.
      IF (.NOT.CHECK) RETURN
      WRITE(KPRINT,997) DBV
      WRITE(KPRINT,996) PERV
      WRITE(KPRINT,995) CSCF
      WRITE(KPRINT,994) FON1
      WRITE(KPRINT,993) FON2
      WRITE(KPRINT,992) ENV
997   FORMAT(1H1,18(/,1H0,20(/,1H ,15F8.2),/,1H,F8.2))
996   FORMAT(1H1,8(/,1H0,20(/,1H,15F8.2),/,1H,F8.4))
995   FORMAT(1H1,(15F8.2))
994   FORMAT(1H1,8(/,1H0,30(/,1H,10E12.5),/,1H,E12.5))
993   FORMAT(1H1,2(/,1H0,15(/,1H,10E12.5),/,1H,E12.5))
992   FORMAT(1H1,151(/,1H,10E12.5))
      RETURN
999   WRITE(KPRINT,998)
998   FORMAT(//10X,*..ERROR..DB,PERCENT CURVE TABLES(TAPE20)
     1   MISSING -- PROGRAM ABORTED*)
      STOP
      END
```

APPENDIX D

TABLE 31 SENSOR DATA

SENSOR DATA					
SCENARIO	TRIAL	OPTIC	THERMAL	ACOUSTIC	TOTAL
DEFENSE TUGV INCLUDED CLEAR/DAY WEATHER μ = 70.78 σ = 20.43	1	74	0	6	80
	2	18	22	4	44
	3	37	41	6	44
	4	21	44	4	80
	5	71	0	5	76
DEFENSE NO TUGV (SOLDIER) CLEAR/DAY WEATHER μ = 39.6 σ = 4.51	1	35	0	0	35
	2	36	0	0	36
	3	42	0	0	42
	4	46	0	0	46
	5	39	0	0	39
OFFENSE TUGV INCLUDED CLEAR/DAY WEATHER μ = 17.4 σ = 5.22	1	21	0	4	25
	2	16	0	3	19
	3	9	2	2	13
	4	8	2	2	18
	5	14	0	4	18
OFFENSE NO TUGV (HMMWV) CLEAR/DAY WEATHER μ = 13.6 σ = 3.05	1	11	[illegible]	0	16
	2	5	7	0	12
	3	15	0	0	19
	4	16	0	0	16
	5	0	9	0	9

TABLE 32 SENSOR DATA CONTINUED

SENSOR DATA (CONTINUED)					
SCENARIO	**TRIAL**	**OPTIC**	**THERMAL**	**ACOUSTIC**	**TOTAL**
DEFENSE TUGV INCLUDED OBSCURED/NIGHT WEATHER μ = 78.00 σ = 6.60	1	0	76	7	83
	2	27	36	8	71
	3	0	79	8	78
	4	0	66	8	78
	5	28	36	11	78
DEFENSE NO TUGV (SOLDIER) OBSCURED/NIGHT WEATHER μ = 28.2 σ = 1.92	1	30	0	0	30
	2	29	0	0	29
	3	25	0	0	25
	4	28	0	0	29
	5	29	0	0	29
OFFENSE TUGV INCLUDED OBSCURED/NIGHT WEATHER μ = 9.6 σ = 2.302	1	0	0	8	12
	2	0	7	8	8
	3	0	9	3	12
	4	1	6	0	7
	5	2	6	0	8
OFFENSE NO TUGV (HMMWV) OBSCURED/NIGHT WEATHER μ = 9.8 σ = .4472	1	0	10	0	10
	2	1	8	0	9
	3	0	10	0	10
	4	4	6	0	10
	5	0	10	0	10

μ: MEAN NUMBER OF DETECTIONS
σ: STANDARD DEVIATION

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